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A State-of-the-Art Review

IT Corp., Pittsburgh, PA

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UNDERGROUND TANK LEAK DETECTION METHODS
A STATE-OF-THE-ART REVIEW

by

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Contract No. 68-03-3069

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This report is a state-of-the-art review of available and developing methods for finding small leaks in underground storage tanks used primarily for gasoline and other liquid petroleum fuels. This review describes (based on information provided by the manufacturers or practitioners) a total of thirty-six volumetric, nonvolumetric, inventory monitoring, and leak effects monitoring detection methods; provides general engineering comments on each volumetric and nonvolumetric leak detection method; and discusses variables which may affect the accuracy of detection methods. The emphasis throughout is on volumetric and nonvolumetric leak detection methods.

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FOREWORD

Today's rapidly developing and changing technologies and industrial products and practices frequently carry with them the increased generation of solid and hazardous wastes. These materials, if improperly dealt with, can threaten both public health and the environment. Abandoned waste sites and accidental releases of toxic and hazardous substances to the environment also have important environmental and public health implications. The Hazardous Waste Engineering Research Laboratory assists in providing an authoritative and defensible engineering basis for assessing and solving these problems. Its products support the policies, programs, and regulations of the Environmental Protection Agency, the permitting and other responsibilities of State and local governments, and the needs of both large and small businesses in handling their wastes responsibly and economically.

This report describes both commercially available and developing techniques for detecting leaks in underground storage tanks, and will be useful to government officials, industry, and those members of the public concerned with this aspect of preventing the pollution of ground water.

For further information, please contact the Land Pollution Control Division of the Hazardous Waste Engineering Research Laboratory.

David G. Stephan, Director
Hazardous Waste Engineering Research Laboratory

PREFACE

This report has been prepared by IT Corporation (IT) under contract with the U.S. Environmental Protection Agency (EPA), to be used as a state-of-the-art overview of available and developing leak detection methods for testing underground tank systems. The descriptions of detection methods and the techniques to compensate for the effects of the variables affecting detection methods have been reviewed by the manufacturer, practitioner, or developer of the detection method. It is expected that this report will result in further evaluation in detection methods to compensate for variables affecting the accuracy of available and developing detection methods.

The variables described in this report should be considered as potential sources of error, especially in the application of volumetric leak detection methods. The applicability and effectiveness of detection methods identified must be determined on an individual test situation basis. The applicability of a detection method will depend upon numerous factors including hydrogeologic, economic, climatic, and conditional considerations.

As an aid to identifying all of the available and developing leak detection methods for underground tank testing, a list of the identified detection methods was published by the Petroleum Equipment Institute (PEI) in its Tulsa letter in August 1984 (together with the request that IT be advised of any other detection methods). In addition, a limited patent search was conducted to identify other leak detection methods for testing underground tanks or tank systems.

ABSTRACT

This report is a state-of-the-art review of available and developing methods for finding small leaks in underground storage tanks used primarily for gasoline and other liquid petroleum fuels. This review describes (based on information provided by the manufacturers or practitioners) a total of thirty-six volumetric, nonvolumetric, inventory monitoring, and leak effects monitoring detection methods; provides general engineering comments on each volumetric and nonvolumetric leak detection method; and discusses variables which may affect the accuracy of detection methods. The emphasis throughout is on volumetric and nonvolumetric leak detection methods.

This report was submitted in fulfillment of Contract No. 68-03-3069 by IT Corporation under the sponsorship of the U.S. Environmental Protection Agency. This report covers a period from July 1984 to January 1985, and work was completed as of June 1985.

CONTENTS

PAGE

DISCLAIMER ii

FOREWORD iii

PREFACE iv

ABSTRACT v

FIGURES xi

TABLES xii

ACKNOWLEDGEMENT xiii

SECTION 1 - INTRODUCTION 1
- STATEMENT OF THE PROBLEM 1
- REPORT OBJECTIVE 2

SECTION 2 - SUMMARY 3

SECTION 3 - CONCLUSIONS 26

SECTION 4 - RECOMMENDATIONS 27

SECTION 5 - VARIABLES AFFECTING LEAK DETECTION METHODS 28
- VOLUMETRIC LEAK DETECTION TESTS 28
  - Temperature 35
  - Water Table 35
  - Tank Deformation 37
  - Vapor Pockets 42
  - Product Evaporation 42
  - Piping Leaks 42
  - Tank Geometry 42
  - Wind 44
  - Vibration 44
  - Noise 44

Preceding page blank

Equipment Accuracy 45
Operator Error 45
Type of Product 45
Power Variation 45
Instrumentation Limitation 45
Atmospheric Pressure 46
Tank Inclination 46
NONVOLUMETRIC LEAK TESTS 46
Temperature 46
Water Table 47
Tank Deformation 47
Vapor Pocket 48
Product Evaporation 48
Piping Leaks 48
Tank Geometry 48
Wind 48
Vibration 48
Noise 48
Equipment Accuracy 49
Operator Error 49
Type of Product 49
Power Variation 49
Instrumentation Limitation 49
Atmospheric Pressure 49
Tank Inclination 49
General Problems 49
INVENTORY CONTROL 50
LEAK EFFECTS MONITORING 50
SECTION 6 - LEAK DETECTION METHODS REVIEW 51
CLASSIFICATION 51
Volumetric (Quantitative) Leak Testing 52
Nonvolumetric (Qualitative) Leak Testing 52

Inventory Control 52
Leak Effects Monitoring 52
LEAK DETECTION TESTING METHODS 52
Volumetric (Quantitative) Leak Testing Methods 52
1- Ainlay Tank Tegrity Testing (TTT) 52
2- ARCO HTC Underground Tank Leak Detector 56
3- Certi-Tec Testing 60
4- "Ethyl" Tank Sentry Testing 63
5- EZY-CHEK Leak Detector 66
6- Fluid-Static (Standpipe) Testing 71
7- Heath Petro Tite Tank and Line Testing (Kent-Moore Testing) 72
8- Helium Differential Pressure Testing 76
9- Leak Lokator LD-2000 Test (Hunter-Formerly Sunmark Leak Detection) 77
10- Mooney Tank Test Detector 82
11- PACE Leak Tester 84
12- PALD-2 Leak Detector 87
13- Pneumatic Testing 89
14- Tank Auditor 90
15- Two-Tube Laser Interferometer System 93
Nonvolumetric (Qualitative) Leak Testing Methods 96
1- Acoustical Monitoring System (AMS) 96
2- Leybold-Heraeus Helium Detector, Ultratest M2 97
3- Smith & Denison Helium Test 98
4- TRC Rapid Leak Detector for Underground Tanks and Pipes 100
5- Ultrasonic Leak Detector, Ultrasound 100
6- VacuTect (Tanknology) 102
7- Varian Leak Detector (SP Y2000 or 938-41) 103
Inventory Monitoring 105
1- Gage Stick 105

2- MFP-414 TLG Leak Detector 105
3- TLS-150 Tank Level Sensor (Veeder-Root) 108
Leak Effects Monitoring 109
1- Collection Sumps 109
2- Dye Method 109
3- Ground Water or Soil Core Sampling 111
4- Interstitial Monitoring in Double-Walled Tanks 111
5- LASP Monitoring System (Leakage Alarm System for Pipe) 112
6- Observation Wells 112
7- Pollulert and Leak-X Detection Systems 114
8- Remote Infrared Sensing 114
9- Surface Geophysical Methods 114
10- U-Tubes 114
11- Vapor Wells 116
REFERENCES 118
APPENDIX - LEAK DETECTION METHODS - MANUFACTURER OR PRACTITIONER PHONE NUMBERS

FIGURES

FIGURE NO.	TITLE	PAGE
1	Temperature Stratification	29
2	Average Gasoline Temperature for All Test Stations	30
3	Mean Temperature Distribution as a Function of Depth for Four Different 24-Hour Periods	31
4	Tank Temperature Stratification and Gradients for a 24-Hour Period After Tank Fill Up	32
5	Location of Temperature Sensors in the SRI Tank	33
6	Delivery Temperatures	34
7	Tank End Deflection	38
8	Change in Tank Volume Due to Tank End Deflections - In Gallons	39
9	Examples of Three Common Vapor Pockets	43
10	Ainlay Tank Tegrity Testing Method	53
11	ARCO Underground Tank Leak Detector	57
12	Certi-Tec Tank Testing System	61
13	"Ethyl" Tank Sentry Kit	64
14	"Ethyl" Tank Sentry Installation	64
15	EZY-CHEK Leak Detector	67
16	EZY-CHEK Leak Detector Installation	68
17	EZY-CHEK Leak Detector Temperature Averaging Probe	68
18	Petro Tite Installation	73
19	Leak Lokator Installation	78
20	Two-Tube Laser Interferometer	94
21	MFP-414 TLG Leak Detector-Sensor Assembly	106
22	MFP-414 TLG Tank Level Gauge & Leak Detector	107
23	Typical Wells for Continuous Gas or Vapor Monitoring	110
24	Examples of Observation Wells	113
25	Example of a U-Tube Installation	115

TABLES

TABLE NO.	TITLE	PAGE
1	Volumetric Leak Detection Methods - General Information	5
2	Nonvolumetric Leak Detection Methods - General Information	8
3	Other Leak Detection Methods - General Information	10
4	Volumetric Leak Detection Methods - General Capabilities	12
5	Nonvolumetric Leak Detection Methods - General Capabilities	14
6	Other Leak Detection Methods - General Capabilities	15
7	Volumetric Leak Detection Methods - Compensation for Effects of Variables	16
8	Nonvolumetric Leak Detection Methods - Compensation for Effects of Variables	22
9	Other Leak Detection Methods - Compensation for Effects of Variables	24
10	Thermal Expansion of Liquids	36
11	Pressure-Height Chart	40
12	Total Force on Tank Ends	40
13	Apparent Loss of Product Volume Due to Force on Tank Ends - In Gallons	41

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SECTION 1

INTRODUCTION

STATEMENT OF THE PROBLEM

In recent years, the increase in leaks from underground gasoline storage tanks has had a significant adverse environmental impact on the United States. Current estimates from government and industry sources are that between 1.5 to 3.5 million underground storage tanks exist in the nation. Estimates of the number of leaking tanks range from 75,000 to 100,000; and 350,000 others may develop leaks within the next five years (1). The 1983 National Petroleum News Factbook Issue forecasts the existence of approximately 140,000 gasoline service stations in the United States at the end of 1983. New York State estimates that 19 percent of its 83,000 active underground gasoline tanks are now leaking. Maine estimates that 25 percent of its 1,600 retail gasoline underground tanks are leaking approximately 11 million gallons yearly. In Michigan 39 percent of ground water contamination incidents are attributed to storage tanks.

One of the primary causes of tank leakage is corrosion of the storage tanks. Product loss from leaking tanks may cause an adverse effect on the environment, endanger lives, reduce income, and require the expenditure of millions of dollars for cleanup. To prevent or reduce the adverse effects of gasoline leakage, an accurate method must be used to determine whether or not an underground tank is leaking.

The 1984 Resource Conservation and Recovery Act (RCRA) amendments regulate underground storage tanks containing petroleum products and substances defined in Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). RCRA regulations specify release detection, prevention, and corrections and require a leak detection system, an inventory control system, and a tank testing (or equivalent system). States are also passing legislation and writing regulations requiring both staged replacement of existing underground tanks and installation of monitoring wells to detect leaks. Performance standards for new tanks will be specified under RCRA and included in various state regulations.

REPORT OBJECTIVE

The objective of this report is to identify existing and developing techniques to detect leaks in underground fuel storage tanks. This objective is accomplished by a review of the manufacturer's description of each method, its capabilities, and its claimed precision and accuracy.

The variables affecting leak detection methods are introduced in Section 5. This information should give the reader an understanding of the major variables and their effects on the accuracy of various leak detection methods. Section 6 presents a description of each detection method based on the available literature from the manufacturer (or practitioner). The descriptions in Section 6 of the manufacturer's techniques for offsetting the effects on each detection method of these major variables are based on information from the manufacturer's literature, reports, and/or verbal communications between the authors and the staff of the manufacturer. This information was reviewed for correctness by most of the manufacturers, practitioners, or developers of the detection methods (instruments). Independent engineering evaluations of error sources for each detection method are provided by the authors. Finally, Tables 1 through 9 in Section 2 summarize the capabilities of the leak detection methods. Information in these tables is primarily from each manufacturer's description and, where noted, from the engineering comments in Section 6. The appendix at the end of this report provides the phone number and contact name of the manufacturer/practitioner for each manufactured leak detection method.

SECTION 2

SUMMARY

Existing and developing leak detection methods were reviewed, and techniques for offsetting the effects of variables which affect accuracy were evaluated. In Tables 1 through 9, general information, general operational capabilities, and compensation for effects of variables discussed in this text are summarized for volumetric, nonvolumetric, and other leak detection methods for underground storage tanks. Wherever it is appropriate, in these summary tables, the information furnished is based on engineering comments and not the manufacturer's claim.

To conduct this survey, the American Petroleum Institute (API) and the Petroleum Equipment Institute (PEI) were contacted for assistance in developing a comprehensive list of available detection methods. A limited patent search was performed to identify methods currently being developed, but not yet available commercially. In all, fifteen volumetric leak testing, seven nonvolumetric leak testing, three inventory monitoring, and eleven leak effects monitoring methods were found.

The information on the following pages (Tables 1 through 9) is based almost entirely on information provided by the manufacturers and practitioners of the detection methods.

TABLE 1. VOLUMETRIC LEAK DETECTION METHODS - GENERAL INFORMATION

Method Description	Principle	Claimed Accuracy (gal/hr)	Calibration During Test	Cost of Testing*	Single Tank Preparation for Test
1. Ainlay Tank Tegrity Testing	• Pressure measurement by a coil type manometer, determine product level change in a propane bubbling system	0.02	Yes	$225/day + Exp. 3 tanks/day (8)	Fill a tank evening before a test
2. ARCO HTC Underground Tank Leak Detector	• Level change measurement by float and light sensing system	0.05	Yes		Adjust the level at 66-76 percent
3. Certi-Tec Testing	• Monitors pressure changes resulting from product level changes	0.05	No		None
4. "Ethyl" Tank Sentry	• Level change magnification by a "J" tube manometer	Sensitive to 0.02 inches level change	No	$300/tank (17)	No deliveries 24 hours prior to a test
5. EZY-CHEK Leak Detector	• Pressure measurement, determine product level change in an air bubbling system	Less than 0.01	Yes	$300/tank (19)	Fill up four hours prior to a test, usually test at night
6. Fluid-Static (Stand-pipe) Testing	• Pressurize a system by a standpipe • Keep the level constant by product addition or removal • Measure rate of volume change	Gross	No	Low	Fill the tank prior to a test

(continued)

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TABLE 1 (continued)

Method	Description	Principle	Claimed Accuracy (gal/hr)	Calibration During Test	Cost of Testing*	Single Tank Preparation for Test
7.	Heath Petro Tite Tank and Line Testing (Kent-Moore)	• Pressurize a system by a standpipe • Keep the level constant by product addition or removal • Measure volume change • Product circulation by pump	Less than 0.05	Yes	$75/1,000 gal (21)	Fill the tank prior to a test
8.	Helium Differential Pressure Testing	• Leak detection by differential pressure change in an empty tank • Leak rate estimation by Bernoulli's equation	Less than 0.05	No		Seal the ports to the atmosphere, empty the tank
9.	Leak Lokator Test Hunter-Formerly Sunmark Leak Detection	• "Principle of Buoyancy" The apparent loss in weight of any object submerged in a liquid is equal to the weight of the displaced volume of liquid	0.05 even at product level at the center of a tank	Yes	$500/tank (25)	Typically fill the tank before testing (if it is possible to fill a tank by the product)
10.	Mooney Tank Test Detector	• Level change measurement with a dip stick	0.02	Yes	$250/tank (27)	Fill the tank 12-14 hours prior to a test
11.	PACE Tank Tester	• Magnification of pressure change in a sealed tank by using a tube and based on manometer principle	Less than 0.05	Yes	Not Commercial	• Fill the tank 12 hours prior to a test • Seal all the ports except fill pipe

(continued)

TABLE 1 (continued)

Method	Description	Principle	Claimed Accuracy (gal/hr)	Calibration During Test	Cost of Testing*	Single Tank Preparation for Test
12.	PALD-2 Leak Detector	• Pressurize system with nitrogen at three different pressures • Level measurement by an electro-optical device • Estimate leak rate based on the size of leak and pressure difference across the leak	Less than 0.05	No	Not commercial	Fill the tank 24 hours prior to a test. All ports must be hermetically sealed
13.	Pneumatic Testing	• Pressurize system with air or other gas • Leak rate measurement by change in pressure	Gross	No	Low	Seal the ports
14.	Tank Auditor	• "Principle of Buoyancy"	0.00001 in the fill pipe 0.03 at the center of a 10.5-foot-diameter tank	Yes	$400/tank	None
15.	Two-Tube Laser Interferometer System	• Level change measurement by laser beam and its reflection	Less than 0.05	Yes	Not Commercial	None

*Charges could be negotiated with manufacturer for different numbers of tank testing and different tank specifications.

( )See References.

TABLE 2. NONVOLUMETRIC LEAK DETECTION METHODS - GENERAL INFORMATION

Method Description	Principle	Claimed Accuracy (gal/hr)	Calibration During Test	Cost of Testing*	Single Tank Preparation for Test
1. Acoustical Monitoring System (AMS)	• Sound detection of vibration and elastic waves generated by a leak in a pressurized system by nitrogen • Triangulation technique to detect leak location	• Does not provide leak rate • Detect leak as low as 0.01 gallons per hour	Does not apply	Not commercial	• Seal all ports prior to a test
2. Leybold-Heraeus Helium Detector, Ultratest M2	• Rapid diffusivity of helium • Mix a tracer gas, with products at the bottom of the tank • Detect helium by a sniffer mass spectrometer	• Does not provide leak rate • Helium could leak through 0.005 inches leak size(38)	Does not apply	By contractor	• Seal all ports prior to a test • Monitoring holes
3. Smith & Denison Helium Test	• Rapid diffusivity of helium • Differential pressure measurement • Helium detection outside a tank	• Provide the maximum possible leak based on the size of the leak (does not provide leak rate) • Helium could leak through 0.005 inches leak size	Does not apply	By contractor	• Seal all ports • Monitoring holes
4. TRC Rapid Leak Detector for Underground Tanks and Pipes	• Rapid diffusion of tracer gas • Mix a tracer gas with product • Detect tracer gas by a sniffer mass spectrometer using a vacuum pump	• Does not provide leak rate • Tracer gas could leak through 0.005 inches leak size(38)	Does not apply	By contractor	• Seal all ports prior to a test • Monitoring holes

(continued)

TABLE 2 (continued)

Method	Description	Principle	Claimed Accuracy (gal/hr)	Calibration During Test	Cost of Testing*	Single Tank Preparation for Test
5.	Ultrasonic Leak Detector (Ultrasound)	• Vacuum the system (5 psi) • Scanning entire tank wall by Ultrasound device • Note the sound due to leak by headphones and register on a meter	• Does not provide the leak rate • A leak as low as 0.001 gallons per hour of air could be detected • A leak through 0.005 inches could be detected	Does not apply	Not commercial	• Seal all ports • Empty the tank
6.	VacuTect (Tanknology)	• Vacuum application at higher than product static head • Detect bubbling noise by hydrophone • Estimate approximate leak rate by experience	• Provide approximate leak rate	Does not apply	$500/tank (44)	• Seal all ports
7.	Varian Leak Detector (SPY2000 or 938-41)	• Similar to Smith & Denison	• Similar to Smith & Denison	Does not apply	By contractor	• Seal all ports • Monitoring holes

*Charges could be negotiated with manufacturer for different numbers of tank testing and different tank specifications.

( )See References.

TABLE 3. OTHER LEAK DETECTION METHODS - GENERAL INFORMATION

Method Description	Principle	Claimed Accuracy	Calibration During Testing	Cost of Testing*	Single Tank Preparation for Test
Inventory Monitoring					
1. Gage Stick	• Product level measurment with dip stick during station's close time	Gross	No	Minimal	None
2. MFP-414 TLG Leak Detector	• Product weight monitoring by pressure and density measurement at the top, middle, and bottom of tank	Sensitive to 0.1 percent of product height change	No	$5,000-$6,000 (equipment cost)	None
3. TLS-150	• Electronic level measurement device • Programmed microprocessor inventory system	Sensitive to 0.1 inches level change	No	$5,000 (equipment)	None
Leak Effect Monitoring					
1. Collection Sumps	• Collection mechanism of product in collection sump through sloped floor under the storage tank	Does not provide leak rate	No	Provided by contractor	None
2. Dye Method	• Hydrocarbon detection through perforated pipe by soluble dye	Does not provide leak rate	No	Provided by contractor	None
3. Ground Water and Soil Sampling	• Water and soil sampling	Does not provide leak rate	Does not apply	Provided by contractor	None
4. Interstitial Monitoring in Double-Walled Tanks	• Monitoring the interstitial space between the walls of double-walled tanks using vacuum or fluid sensors	Does not provide leak rate	No	By tank manufacturer	None
5. L.A.S.P.	• Diffusion of gas and vapor to a plastic material	Does not provide leak rate	Does not apply	Provided by contractor	None

(continued)

TABLE 3 (continued)

Method	Description	Principle	Claimed Accuracy	Calibration During Testing	Cost of Testing*	Single Tank Preparation for Test
6.	Observation Wells	• Product sensing in liquid through monitoring wells at areas with high ground water	Does not provide leak rate	No	Provided by contractor	None
7.	Pollulert and Leak-X	• Difference in thermal conductivity of water and hydrocarbon through monitoring wells	Does not provide leak rate	Does not apply	Provided by contractor	None
8.	Remote Infrared Sensing	• Determine soil temperature characteristic change due to the presence of hydrocarbons	Does not provide leak rate	Does not apply	Provided by contractor	None
9.	Surface Geophysical Methods	• Hydrocarbon detection by ground penetrating radar, electromagnetic induction, or resistivity techniques	Does not provide leak rate	Does not apply	Provided by contractor	None
10.	U-Tubes	• Product sensing in liquid • Collection sump for product directed through a horizontal pipe installed under a tank	Does not provide leak rate	No	Provided by contractor	None
11.	Vapor Wells	• Monitoring of vapor through monitoring well	Does not provide leak rate	No	Provided by contractor	None

*Charges could be negotiated with manufacturer for different numbers of tank and different tank specifications.

TABLE 4. VOLUMETRIC LEAK DETECTION METHODS - GENERAL CAPABILITIES

Method	Description	Detects Leak In/Out	Differentiates Leak in Piping or Tank	Tests Single or Multiple Tanks	Has Potential for Printed Readout	Tests at Pressure not Greater than 5 PSIG	Detects Leak Only Below Normal High Fill Level	Total Downtime for Testing	Requires Empty/Full Tank for Test
1.	Ainlay Tank Tegrity Testing	Both	Yes	2	No	Yes	No	10-12 hours (filled a night before 1.5 hours testing)	Full
2.	ARCO HTC Underground Tank Leak Detector	Both	Yes	4	Yes	Yes	Yes	4-6 hours	No
3.	Certi-Tec Testing	Both	Yes	2	Yes	Yes	No	4-6^a hours	Full
4.	"Ethyl" Tank Sentry Testing	Both	Tank Testing	1	No	Yes	Yes	Typically 10 hours	No
5.	EZY-CHEK Leak Detector	Both	Yes	2	Yes	Yes	No	4-6^a hours (2 hours waiting after fill up, 1 hour test)	Full
6.	Fluid-Static (Standpipe) Testing	Both	No	1	No	Yes	No	Several days	Full
7.	Heath Petro Tite Tank and Line Testing (Kent-Moore Testing)	Both	Yes	4	No	Sometimes No	No	6-8 hours	Full
8.	Helium Differential Pressure Testing	Both	No	1	Yes	Yes	No	Minimum 48 hours	Empty
9.	Leak Lokator LD2000 Test (Hunter-Formerly Sunmark Leak Detection)	Both	Yes	3	Yes	Yes	No	3-4 hours	Typically full

(continued)

TABLE 4 (continued)

Method	Description	Detects Leak In/Out	Differentiates Leak in Piping or Tank	Tests Single or Multiple Tanks	Has Potential for Printed Readout	Tests at Pressure not Greater than 5 PSIG	Detects Leak Only Below Normal High Fill Level	Total Downtime for Testing	Requires Empty/Full Tank for Test
10.	Mooney Tank Test Detector	Both	Yes	3	No	Yes	No	14-16 hours (12-14 hours waiting after fillup, 1-2 hour test)	Full
11.	PACE Tank Tester	Both	Tank Testing	1	No	Yes	Yes	14 hours	Full
12.	PALD-2 Leak Detector	Both	No	1	Yes	No	No	14 hours (preferably a day before, 1 hour fill testing, include sealing time)	Full
13.	Pneumatic Testing	Both	No	1	No	Try to keep below 5 psi but some times exceeds 5 psi	No	Several hours	No
14.	Tank Auditor	Both	Yes	1	Yes	Yes	No	1.5-3 hours	Typically full
15.	Two-Tube Laser Interferometer System	Both	Yes	1	Yes	Yes	No	4-5[b] hours	No (at existing level)

[a] Including the time for tank end stabilization with testing with standpipe.

[b] Including 1 to 2 hours for reference tube temperature equilibrium.

TABLE 5. NONVOLUMETRIC LEAK DETECTION METHODS - GENERAL CAPABILITIES

Method	Description	Detects Leak In/Out	Differentiates Leak in Piping or Tank	Tests Single or Multiple Tanks	Has Potential For Printed Readout	Tests at Pressure not Greater Than 5 PSIG	Detects Leak Only Below Normal High Fill Area	Total Downtime for Testing	Requires Empty/Full Tank for Test
1.	Acoustical Monitoring System (AMS)	Does not differentiate	No	1	Yes	No	Yes	1-2 hours	No
2.	Leybold-Heraeus Helium Detector, Ultratest M2	Does not differentiate	Partially	Several	Yes	Yes	No	None	No
3.	Smith & Denison Helium Test	In a 24-hour test	Partially	1	Yes	Yes	No	Few-24 hours (exclude sealing time)	Empty
4.	TRC Rapid Leak Detector for Underground Tanks and Pipes	Does not differentiate	Partially	Several	Yes	Yes	No	None	No
5.	Ultrasonic Leak Detector (Ultrasound)	Does not differentiate	Yes	Several	Yes	Vacuum	No	Few hours (including tank preparation and 20-minute test)	Empty
6.	VacuTect (Tanknology)	Differentiates	Yes	1	Yes	Vacuum	No	1 hour	No
7.	Varian Leak Detector (SPY2000 or 938-41)	In a 24-hour test	Partially	1	Yes	Yes	No	Few-24 hours (exclude sealing time)	Empty

TABLE 6. OTHER LEAK DETECTION METHODS - GENERAL CAPABILITIES

Method	Description	Detects Leak In/Out	Differentiates Leak In Piping of Tank	Tests Single or Multiple Tanks	Has Potential for Printed Readout	Tests at Pressure not Greater than 5 PSIG	Detects Leak Only Below Normal High Fill Area	Total Downtime for Testing Testing	Requires Empty/Full Tank for Test
Inventory Monitoring									
1.	Gage Stick	Both	No	Single	No	Yes	Yes	Variable[a]	No
2.	MFP-414 TLG Leak Detector	Both	No	6	Yes	Yes	Yes	None	No
3.	TLS-150 Tank Level Sensor (Veeder-Root)	Both	No	4	Yes	Yes	Yes	None	No
Leak Effect Monitoring		Out	No	Several[b]	Yes[c]	Does not apply	Does not apply	None	No

[a] At the station's close of business and again at start of day.

[b] Except Interstitial Monitoring in double-walled tank and U-Tubes which are used for single tank monitoring.

[c] Except Dye Method.

TABLE 7. VOLUMETRIC LEAK DETECTION METHODS - COMPENSATION FOR EFFECTS OF VARIABLES[*]

Variable Method	Temperature	Ground Water Masking	Tank End Deflection	Vapor Pockets	Product Evaporation	Wind
1. Ainlay Tank Tegrity Testing	• 3 temperature sensors • 0.01 °F accuracy	May conduct testing when the leak is completely masked[+]	• Overnight waiting after tank fill up • If tank is filled one hour before testing, the tank deflection is recognized by evaluation of test results	If the vapor pocket is recognized, the tank top will be excavated and the vapor is removed by drilling	• Use propane gas to reduce evaporation • 20-minute testing (short testing intervals)	Not compensated[+]
2. ARCO HTC Underground Tank Leak Detector	Not affected by temperature change	May conduct testing when the leak is completely masked[+]	• No effect (since the test is conducted at normal conditions) • Test continues to obtain equal leak at two consecutive tests	Not applicable	Saturate the vapors on top of product before test by circulation of product	Partially compensated[+]
3. Certi-Tec Testing	• 5 or more temperature sensors • 0.01°F accuracy	Conduct test by standpipe if water table is suspected	Recognized by test results evaluation	• Not applicable, when the test is conducted below the fill pipe • Using standpipe to stabilize vapor pocket	No compensation when the test is performed without the standpipe (long testing)	Partially compensated[+]
4. "Ethyl" Tank Sentry Testing	Thermometer measurement at the beginning and end of a test	May conduct test while the leak is completely or partially masked by variations of the tank's internal forces due to temperature and pressure changes	No product delivery 24 hours prior to a test	Not applicable	No compensation during 10-hour testing	Not affected
5. EZY-CHEK Leak Detector	• Averaging temperature coil • 0.001 °F accuracy	Conduct test by standpipe if water table is suspected	Recognized by test results evaluation	• Could be released by a float tube • Using standpipe to stabilize vapor pocket	• The testing time is short • Overnight testing (usually) • Could use standpipe to reduce evaporation	Partially compensated by printed result evaluation[+]

(continued)

TABLE 7 (continued)

Vibration	Noise	Tank Geometry	Instrumentation Limitation	Operator Error	Atmospheric Pressure	Inclined Tank	Power Variation
Not compensated[+]	Not affected	• Not compensated for temperature compensation[+] • Reduced by calibration[+]	Leak rate measurement when the volume change is less than 0.06 gallons during testing[+]	Insignificant	Not affected	By calibration	Not affected
Partially compensated[+]	Not affected	Not affected	No limitation for typical tank testing (4-inch fill pipe)	Insignificant	Not affected	By calibration	Not compensated
Partially compensated[+]	Not affected	Not compensated for temperature compensation[+]	No limitation for typical tank testing (4-inch fill pipe)	Insignificant	Not affected	• Compensated when tests by standpipe • Not compensated when tests below fill pipe	Not compensated
Not affected	Not affected	Not compensated for leak volume calibration[+]	• No limitation for typical tank testing (4-inch fill pipe) • Minimum 20 inches of product	Insignificant	Not affected	Not compensated	Not affected
Partially compensated by result evaluation and/or by using standpipe[+]	Not affected	Not compensated for temperature compensation[+]	No limitation for typical tank testing (4-inch fill pipe)	Insignificant	Not affected	By calibration	Not affected

(continued)

TABLE 7 (continued)

Variable Method	Temperature	Ground Water Masking	Tank End Deflection	Vapor Pockets	Product Evaporation	Wind
6. Fluid-Static (Standpipe Testing)	No compensation	Tests by standpipe	No compensation	No compensation	Not compensated	Not affected
7. Heath Petro Tite Tank and Line Testing (Kent-Moore Testing)	• One temperature sensor • 0.003 °F accuracy • Product circulation	Tests by standpipe	Stops the end deflection within 2 hours by test results evaluation	The presence of vapor pockets is recognized by observing bubbles in the standpipe	The graduate top is capped	Not affected
8. Helium Differential Pressure Testing	Use reference tube	May conduct test while the leak is completely or partially masked by variation of the tank's internal forces due to pressure changes	Test is conducted within 48 hours	Not applicable	Not applicable	Not affected
9. Leak Lokator LD2000 Test (Hunter-Formerly Sunmark Leak Detection)	• One temperature sensor at midvolume • 0.001 °F accuracy • Three temperature sensors at unusual conditions	May conduct testing when the leak is completely masked[+]	• The end deflection occurs immediately after fill up • 1.5 hours waiting for temperature adjustment	• Compensate if the pocket is released • Not affected during in-tank testing	Compensated by a hollow sensor filled with product	Partially compensated[+]
10. Mooney Tank Test Detector	• Five temperature sensors • 0.001 °F accuracy	May conduct testing when the leak is completely masked[+]	Tests 12 to 14 hours after filling	No compensation	Compensated by using an evaporation cup	Not compensated[+]

(continued)

TABLE 7 (continued)

Vibration	Noise	Tank Geometry	Instrumentation Limitation	Operator Error	Atmospheric Pressure	Inclined Tank	Power Variation
Not affected	Not affected	Not affected	No limitation for typical tank testing (4-inch fill pipe)	Insignificant	Compensated	Not affected	Not affected
Not affected	Not affected	Not compensated for temperature compensation[+]	No limitation for typical tank testing (4-inch fill pipe)	Insignificant	Not affected	By calibration	Not affected
Not affected	Not affected	Not compensated[+]	No limitation for typical tank testing (4-inch fill pipe)	Significant potential (including improper sealing)[+]	Not affected	Not affected	Not compensated
Partially compensated[+]	Not affected	Not compensated for temperature compensation[+]	Sometimes due to tank inclination[+]	Insignificant	Compensated	By calibration	Not compensated
Not compensated[+]	Not affected	Not compensated for temperature compensation[+]	No limitation for typical tank testing (4-inch fill pipe)	Insignificant	Not affected	By calibration	Not affected

(continued)

TABLE 7 (continued)

Variable Method	Temperature	Ground Water Masking	Tank End Deflection	Vapor Pockets	Product Evaporation	Wind
11. PACE Tank Tester	• Three Thermocouples • 0.01°F accuracy	May conduct testing when the the leak is completelv masked	Tests 12 hours after filling	Not applicable	Compensated in calculation	Not compensated
12. PALD-2 Leak Detector	Due to short testing time	Tests at least at three different pressures	The effect is minimized by short testing time (15 min.)	Must be released at any cost	Not applicable	Not affected
13. Pneumatic Testing	No compensation	May conduct test while the leak is masked completely or partially by variation of tank's internal forces due to temperature or pressure changes	The effect is reduced when the testing time is increased	Not applicable	Not applicable	Not affected
14. Tank Auditor	Use reference tube	The test is performed at two different levels	Test at normal operating conditions or 3 to 6 hours after delivery	• Not compensated during testing in a filled tank • Not applicable during in-tank testing	• Short testing • Compensated by temperature probe	Compensated*
15. Two-Tube Laser Interferometer System	Use reference tube	If the test shows no leak, the complete masking effect could be checked by changing the product level	Test at normal operating conditions	Not applicable during in-tank testing	• Short testing • Compensated sated by reference tube	Compensated

(continued)

TABLE 7 (continued)

Vibration	Noise	Tank Geometry	Instrumentation Limitation	Operator Error	Atmospheric Pressure	Inclined Tank	Power Variation
Not affected	Not affected	Compensated by calibration	Thermocouple accuracy	Insignificant	Compensated	Not affected	Not affected
Not compensated	Not affected	Not affected	No limitation for typical tank testing (4-inch fill pipe)	Significant (including improper sealing)[+]	Not affected	Not compensated	Not compensated
Not affected	Not affected	Not affected	No limitation for typical tank testing (4-inch fill pipe)	Significant (including improper sealing)[+]	Not affected	Not affected	Not affected
Not compensated[+]	Not affected	Compensated by calibration	Sometimes due to tank inclination	Insignificant	Not Affected	By calibration	Not compensated
Compensated[+]	Not affected	Compensated by calibration	Sometimes due to tank inclination[+]	Insignificant	Compensated	Compensated	Not compensated

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[*] The type of liquid petroleum fuel does not affect any nonvolumetric leak detection method except the accuracy of reading of tests using "Ethyl" Tank Sentry may or may not be affected by oxygenates (alcohol).

[+] Based on the engineering comments.

TABLE 8. NONVOLUMETRIC LEAK DETECTION METHODS - COMPENSATION FOR EFFECTS OF VARIABLES*

Variable Method	Temperature	Ground Water Masking	Tank End Deflection	Vapor Pockets	Product Evaporation	Wind
1. Acoustical Monitoring System (AMS)	Not affected	Compensated	Not affected	Not applicable	Not applicable	Not affected
2. Leybold-Heraeus Helium Detector, Ultratest M2	Not affected	Compensated if aware of water table	Not affected	Not applicable	Not applicable	Not affected
3. Smith & Denison Helium Test	By using reference tube for leak rate approximation	Compensated if aware of water table	Not affected	Not applicable	Not applicable	Not affected
4. TRC Rapid Leak Detector for Underground Tanks and Pipes	Not affected	Compensated if aware of water table	Not affected	Not applicable	Not applicable	Not affected
5. Ultrasonic Leak Detector, Ultrasound	Not affected	Compensated by vacuum	Not affected	Not applicable	Not applicable	Not affected
6. VacuTect (Tanknology)	Not affected	Compensated by vacuum	Not affected	Not applicable	Not applicable	Not affected
7. Varian Leak Detector (SPY 2000 or 938-41)	By using reference tube for leak rate approximation	Compensated if aware of water table	Not affected	Not applicable	Not applicable	Not affected

(continued)

TABLE 8 (continued)

Vibration	Noise	Tank Geometry	Instrumentation Limitation	Operator Error[+]	Atmospheric Pressure	Inclined Tank	Power Variation
Not affected	Not affected	Not affected	None	Significant (including improper sealing)	Not affected	Not affected	Not affected
Not affected	Not affected	Not affected	None	Significant (including improper sealing)	Not affected	Not affected	Not affected
Not affected	Not affected	Not affected	None	Significant (including improper sealing)	Not affected	Not affected	Not affected
Not affected	Not affected	Not affected	None	Significant (including improper sealing)	Not affected	Not affected	Not affected
Not affected	Not affected	Not affected	None	Significant (including improper sealing)	Not affected	Not affected	Not affected
Not affected	Not affected	Not affected	None	Significant (including improper sealing)	Not affected	Not affected	Not affected
Not affected	Not affected	Not affected	None	Significant (including improper sealing)	Not affected	Not affected	Not affected

[*] The type of a liquid petroleum fuel does not affect any nonvolumetric detection methods.

[+] Based on the engineering comments.

TABLE 9. OTHER LEAK DETECTION METHODS - COMPENSATION FOR EFFECTS OF VARIABLES*

Variable Method	Temperature	Ground Water Masking	Tank End Deflection	Vapor Pockets	Product Evaporation	Wind
Inventory Control:						
1. Gage Stick	Not compsated	Not compensated	By permanent monitoring	Not applicable	Not compensated	Not compensated
2. MFP-414 TLG Leak Detector	Not affected	By permanent monitoring	By permanent monitoring	Not applicable	Not compensated	Not affected
3. TLS-150 Tank Level Sensor (Veeder-Root)	One temperature sensor	By permanent monitoring	By permanent monitoring	Not applcable	Not compensated	Not affected
Leak Effects Monitoring:	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable

(continued)

TABLE 9 (continued)

Vibration	Noise	Tank Geometry	Instrumentation Limitation	Operator Error	Atmospheric Pressure	Inclined Tank	Power Variation
Not compensated	Not applicable	Not compensated	None	Insignificant	Not compensated	Not compensated	Not applicable
Not affected	Not affected	Not compensated for temperature compensation[+]	None	Not affected	Not affected	Not compensated	Not compensated
Not affected	Not affected	Not compensated for temperature compensation[+]	None	Not affected	Not affected	Not compensated	Not compensated
Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Not compensated

[*] The type of a liquid petroleum fuel does not affect the detection methods.
on the engineering comments.

[+] Based on the engineering comments.

SECTION 3

CONCLUSIONS

The conclusions listed below are based on the review of leak detection methods described in this report.

1. Variables affect the testing results of available or developing volumetric, nonvolumetric, and in-tank monitoring methods used for leak detection of underground tank systems. These variables are potential sources of errors in using the detection methods successfully. The importance of each variable may vary due to the characteristics of the tank being tested and to such test conditions as the temperature of additional product used to fill a tank prior to testing, depth of the water table, tank deformation, random variation of ambient temperature or pressure, tank inclination, product vapor pressure, and tank age.

2. The 36 methods identified include 15 volumetric leak detection, 7 nonvolumetric leak detection, 3 in-tank monitoring, and 11 leak effects monitoring methods.

3. Detection methods attempt to compensate for variables affecting accuracy in various ways.

4. Available data on the performance evaluation of the leak detection methods reviewed were not adequate to determine their relative accuracy.

SECTION 4

RECOMMENDATIONS

The accuracy and precision of volumetric leak detection methods (at least) should be determined in order to permit selection of the ones appropriate to any specific need. A cost-effective procedure is to make use of signal/noise theory and a high quality data base to estimate the likely performance of each method under a variety of representative conditions, and to verify performance by evaluating the method under a few, selected, controlled conditions in a full-scale test apparatus.

SECTION 5

VARIABLES AFFECTING LEAK DETECTION METHODS

The capability of leak detection methods to accurately measure rates of leakage is affected by variables, as well as the detection method itself. The principal variables and the way they affect accuracy are discussed in this section. This discussion of variables precedes the description of leak detection methods in Section 6 to provide background information important to an understanding of the detection methods.

Principal variables which affect the accuracy of most of the available leak detection methods are:

- Temperature Change
- Water Table
- Tank Deformation
- Vapor Pockets
- Product Evaporation
- Piping Leaks
- Tank Geometry
- Wind
- Vibration
- Noise
- Equipment Accuracy
- Operator Error
- Type of Product
- Power Variation
- Instrumentation Limitation.
- Atmospheric Pressure
- Tank Inclination

The effects attributable to variables upon the ability to conduct leak detection tests for different detection methods are discussed in this section. The current methods used to compensate for the variables are discussed in Section 6 of this report.

VOLUMETRIC LEAK DETECTION TESTS

Volumetric leak detection tests identify the leak or determine leak rate based on the measurement of properties associated with a change in volume. Certain variables affect the volume change or the measurement of the volume change.

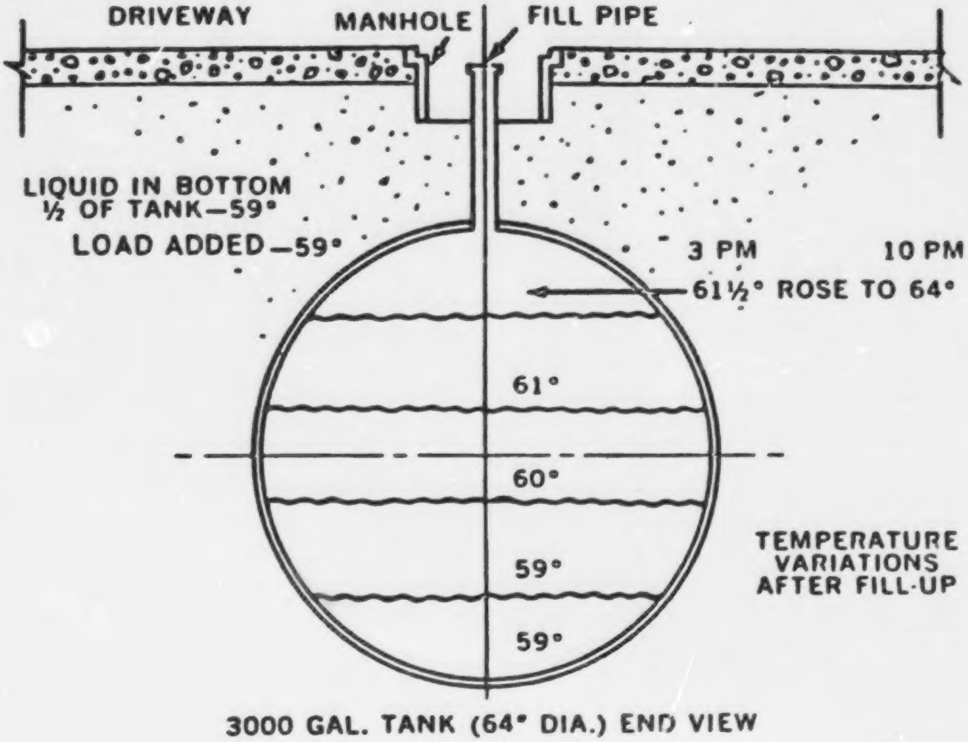
DRIVEWAY
MANHOLE
FILL PIPE
LIQUID IN BOTTOM ½ OF TANK—59°
LOAD ADDED—59°
3 PM
10 PM
61½° ROSE TO 64°
61°
60°
59°
59°
TEMPERATURE VARIATIONS AFTER FILL-UP
3000 GAL. TANK (64" DIA.) END VIEW

Figure 1. Temperature Stratification (4)

Ref: Heath Consultants, Inc. Petro Tite Tank Test Bulletin

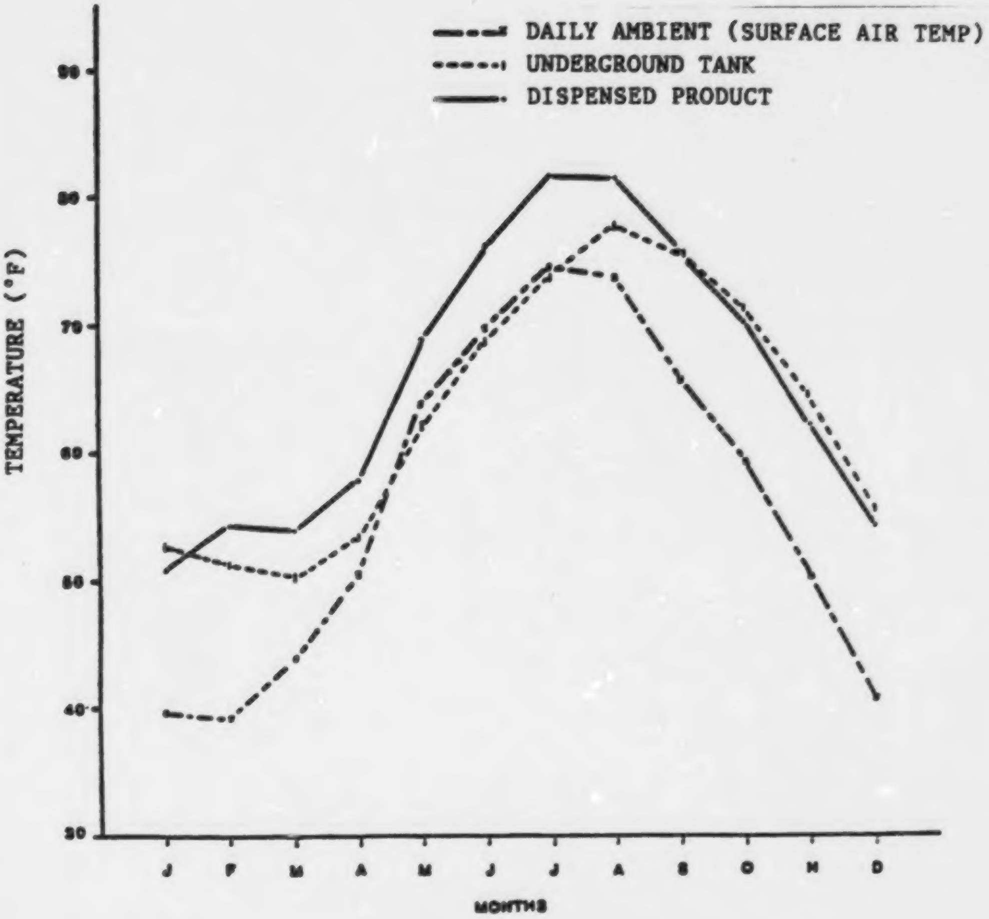

Figure 2. Average Gasoline Temperature For All Test Stations (5)

Ref: API Publication No. 4278

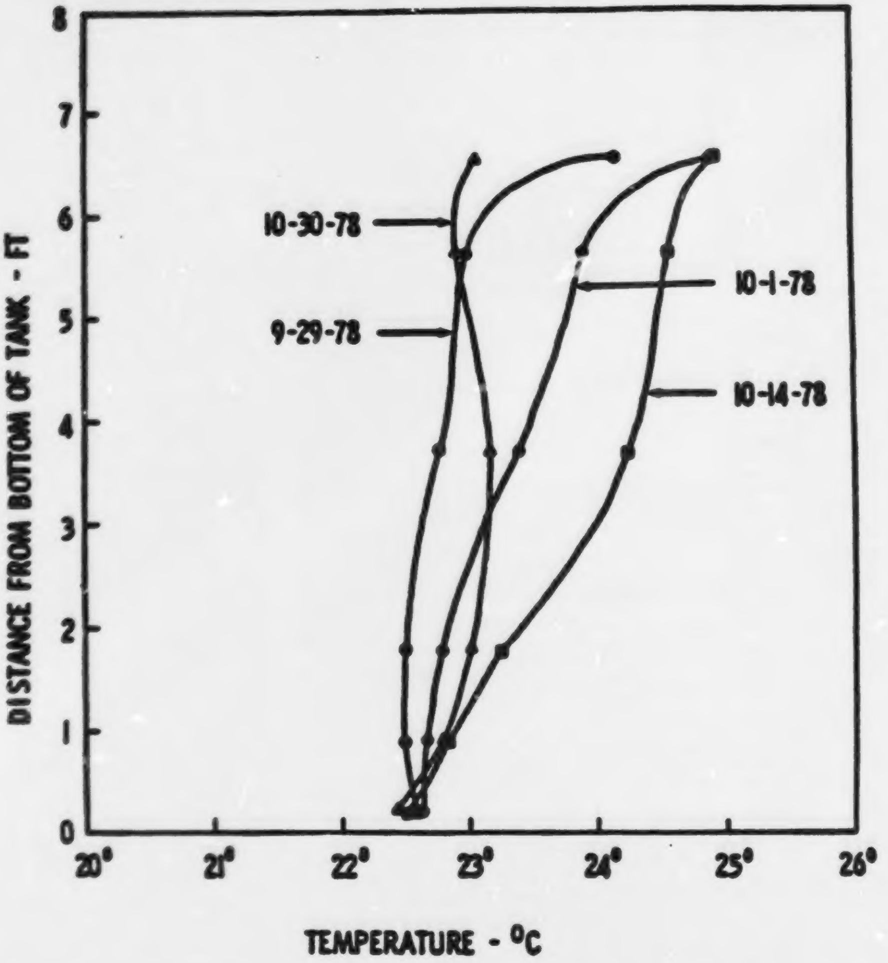

Figure 3. Mean Temperature Distribution As A Function Of Depth For Four Different 24-Hour Periods (5)

Ref: SRI International, Project 7637, Conducted for API
Technical Report 1, June 1979

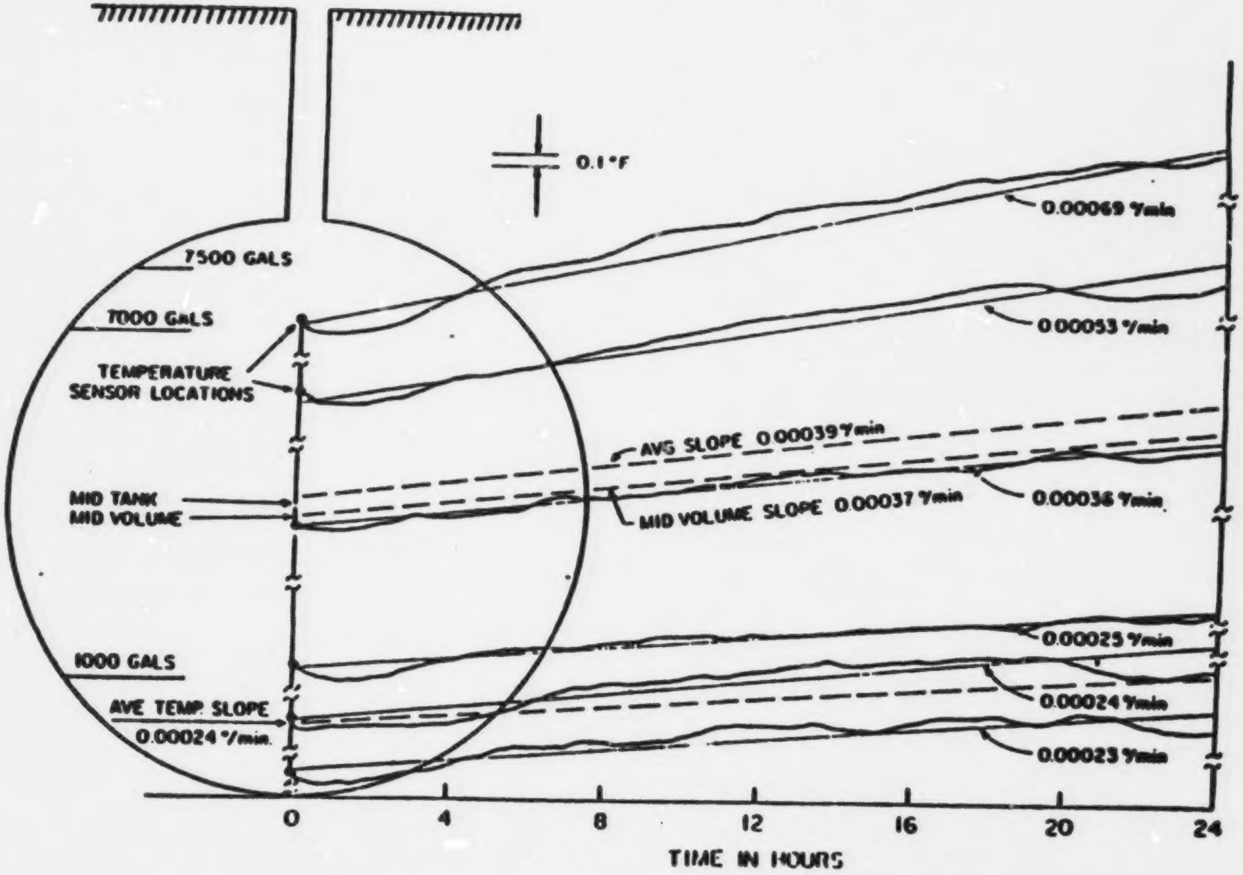

Figure 4. Tank Temperature Stratification And Gradients For A 24-Hour Period After Tank Fill Up (5)

Ref: SRI International, Project 7637, Conducted for API Technical Report, June 1979

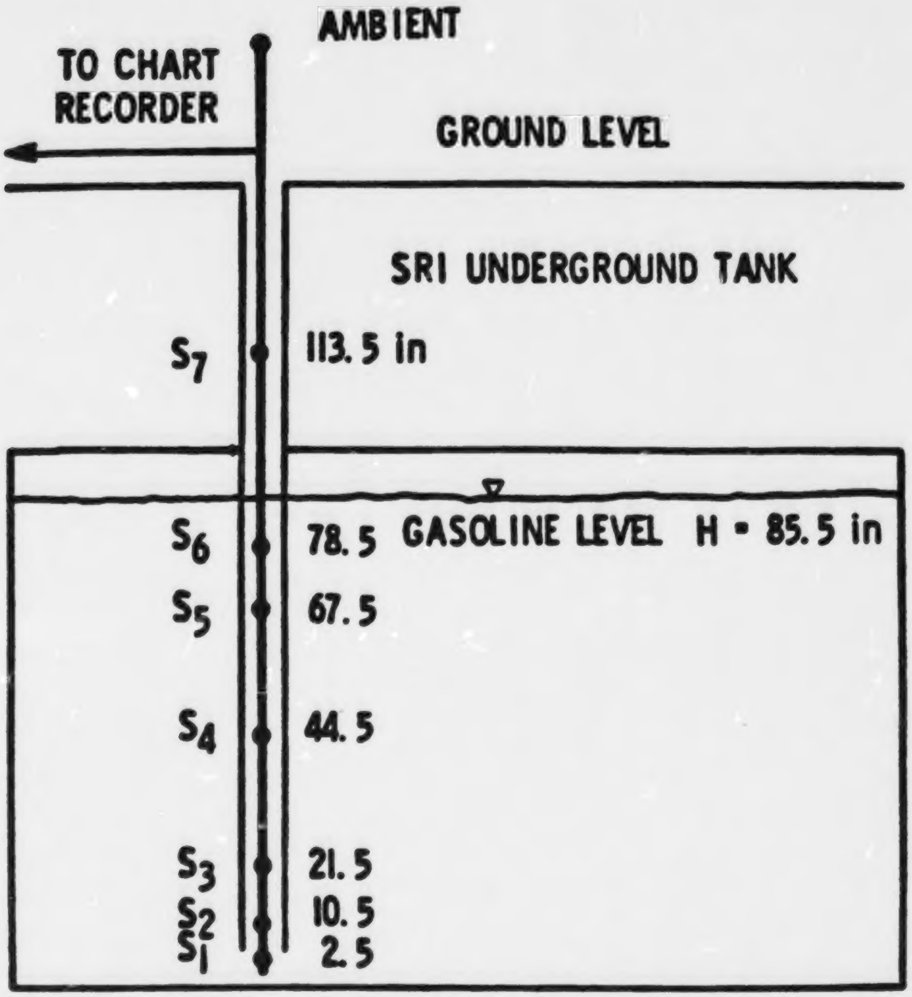
AMBIENT
TO CHART RECORDER
GROUND LEVEL
SRI UNDERGROUND TANK
S_7
113.5 in
S_6
78.5
GASOLINE LEVEL H = 85.5 in
S_5
67.5
S_4
44.5
S_3
21.5
S_2
10.5
S_1
2.5

Figure 5. Location Of Temperature Sensors In The SRI Tank (5)

Ref: SRI International, Project 7637, Conducted for API Technical Report 1, June 1979

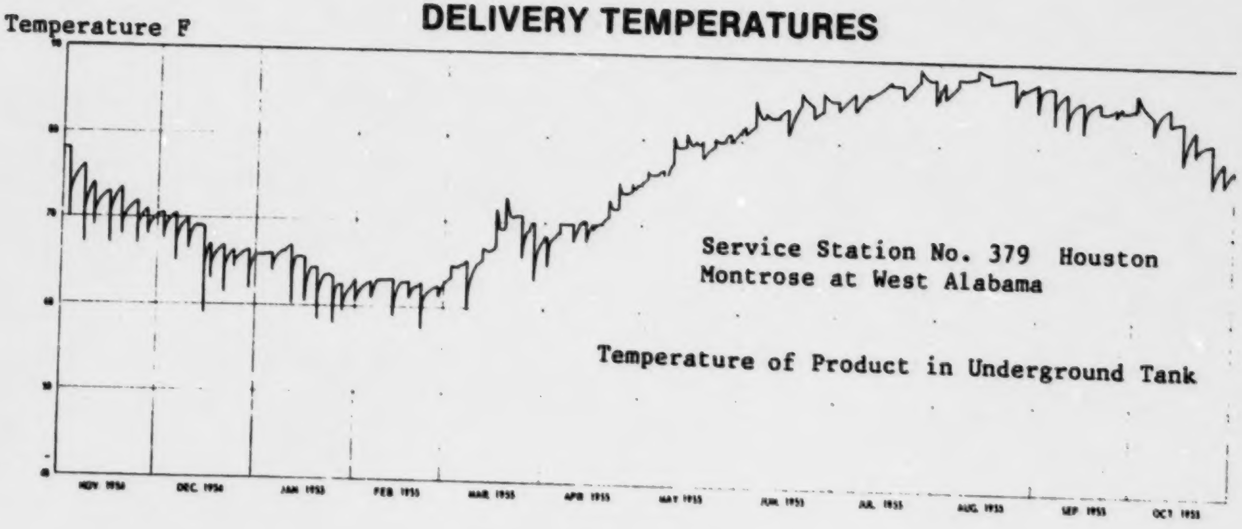

Figure 6. Delivery Temperatures

Ref: Heath Consultants, Inc., Petro Tite Tank Tester Bulletin

Figure 6 shows the graphed temperature recordings for an entire year by combining the results of 52 weekly graphs (4). The vertical lines, either down or up, show the immediate effect of the delivery on the tank temperature and the curving lines show the gradual return to underground temperatures.

The graph also shows a seasonal change of 30 degrees Fahrenheit in underground temperatures occurring even in south Texas. Much greater differences between summer and winter would exist further north and particularly in those areas of the country noted for hot summers and cold winters.

Ref: Heath Consultants, Inc., Petro Tite Tank Tester Bulletin

Temperature

Changes in temperature cause expansion, or contraction, in the product and in tank dimensions. Due to the insignificant thermal coefficient of expansion for steel (fiberglass has a higher thermal expansion than steel) and existence of external factors (e.g., water table and fill material physical effects), the thermal variation of the tank cannot be measured during the occurrence of a leak and small temperature changes. The product volume change can be measured because it is much more sensitive to temperature change. When liquid is added to fill a tank for testing, several days may be required before the liquid stabilizes to ground temperature; however, ground temperature is also constantly changing (and thus prevents stabilization of the system's temperature). The rate of temperature change in the first day or two after addition of liquid will generally be in the range of 0.02 to 0.25 degrees Fahrenheit per hour (3). Temperature changes occur because of the following conditions (Figures 1 through 6) (4,5):

- Hot days
- Cool nights
- Sunshine
- Clouds
- Rain
- Water table
- Type and compaction of fill material.

Two important temperature effects should be considered: volume change and stratification. Gasoline has an expansion coefficient of 0.00068 gallons per degree Fahrenheit (Table 10) (4). To detect leaks as small as 0.05 gallons per hour, a change of 0.01 degrees Fahrenheit per hour in a 10,000-gallon tank may cause a 0.068-gallon change in the product volume per hour, thus offsetting or amplifying an observed leak rate. This temperature effect could be eliminated by accurate temperature measurement. However, the stratification normally present in underground tanks should also be considered. Stratification is due to the variation of product temperature from the top to the bottom of the tank. The top layer temperature may be several degrees higher than the bottom layer. The layer temperatures usually change at different rates at different levels, which makes the temperature measurement more complicated.

Water Table

Hydrostatic head and surface tension forces caused by ground water outside an underground storage tank may mask tank leaks partially or completely. Such leaks may take the form either of product leaving the tank or of ground water entering. When the forces are equal at two sides of a leak opening before or during the testing period, a complete masking effect occurs. The chance of this situation occurring increases

TABLE 10. THERMAL EXPANSION OF LIQUIDS (4)

Ref: Heath Consultants, Inc., Petro Tite Tank Tester Bulletin

TYPE OF PRODUCT	VOLUMETRIC COEFFICIENT OF EXPANSION PER DEGREE F
Benzol (benzene)	0.00071
Diesel fuel	0.00045
Ethyl alcohol	0.00062
Fuel oil #1	0.00049
Fuel oil #2	0.00046
Fuel oil #3	0.0004
Gasohol	
0.10 Ethyl + 0.90 Gasoline	0.000674
0.10 Methyl + 0.90 Gasoline	0.000684
Gasoline	0.00068
Hexane	0.00072
Jet fuel (FP 4)	0.00056
Kerosene	0.00049
Methyl alcohol	0.00072
Stove oil	0.00049
Tuluol (toluene)	0.00063
Water at 68°F	0.000115

These are average values and may vary. If there is any doubt, the product should be checked with a hydrometer.

when the testing method is performed on a tank which is not completely filled and especially when no product is added or removed for testing. The level of ground water may vary seasonally or because of intensity and duration of rainfall. To evaluate the masking effect, the relationship between the product level inside the tank and the ground water level outside the tank system must be known.

Tank Deformation

Changes or distortions of the tank due to significant changes in pressure or temperature can cause an apparent volume change in the product. This is called the tank deformation effect (Figures 7 and 8) and may be affected by the wetness and nonhomogeneous properties of backfill material around the tank (4), the material of tank construction, the thickness of the tank shell, the age of the tank, and forces due to ground water level exerted on the tank. The tank deformation effect is uncontrollable and different for every tank.

The construction of steel tanks is such that distortion effects of the flat ends are generally much greater than that of the cylindrical sides (the reverse is generally true for fiberglass tanks). The pressure within a tank will vary with the specific gravity of the liquid and the liquid height above the bottom of the tank. These pressures can be computed for any height of the tank from Table 11 (4). The total change of the force, in tons, at various pressure changes on each end of a typical steel tank is shown in Table 12 (4).

In some methods for testing tanks with large diameters, the stabilization time for tank end deflection may be more than 36 hours. The stabilization time for deflection of an underground tank is important because the apparent product volume loss caused by tank end deflection cannot be measured and may mask the occurrence of a leak. For example, in a 96-inch-diameter steel tank, the apparent loss of product volume is 1.957 gallons for 1/16-inch tank end deflection. If this volume change occurs within one hour and if it occurs during the test period, it will offset the testing accuracy and the tank will appear to be leaking. The magnitude of apparent volume change for various deflections of a given size steel tank, when it is filled, can be found in Table 13 (4), Figure 8 (5), or can be calculated from the following formula (4):

$$V_T = [\frac{\pi}{2}(r^2 + \frac{h^2}{3})h][2]$$

where V_T = total volume change due to tank end deflections, in.^{3},

r = tank radius, in., and

h = deflection of tank end, in.

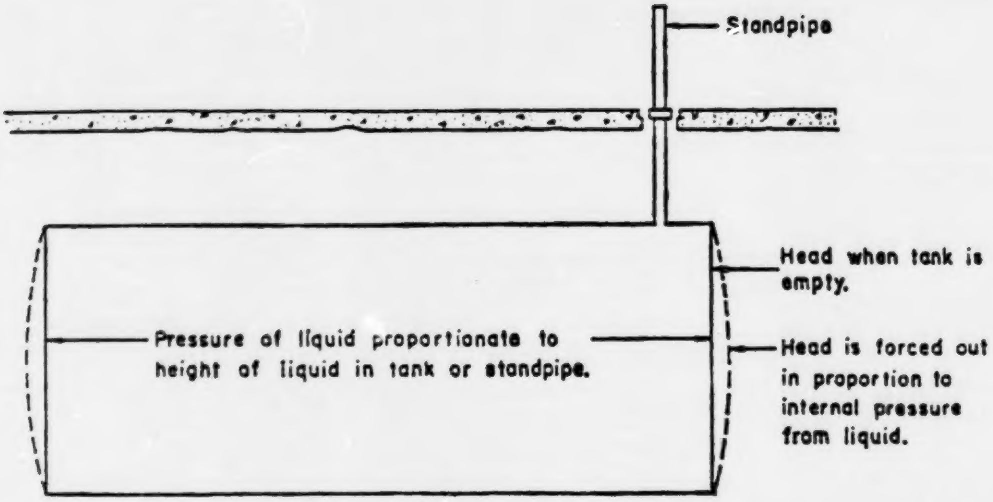
Standpipe
Head when tank is empty.
Pressure of liquid proportionate to height of liquid in tank or standpipe.
Head is forced out in proportion to internal pressure from liquid.

Figure 7. Tank End Deflection (4)

Ref: Heath Consultants, Inc. Petro Tite Tank Tester Bulletin

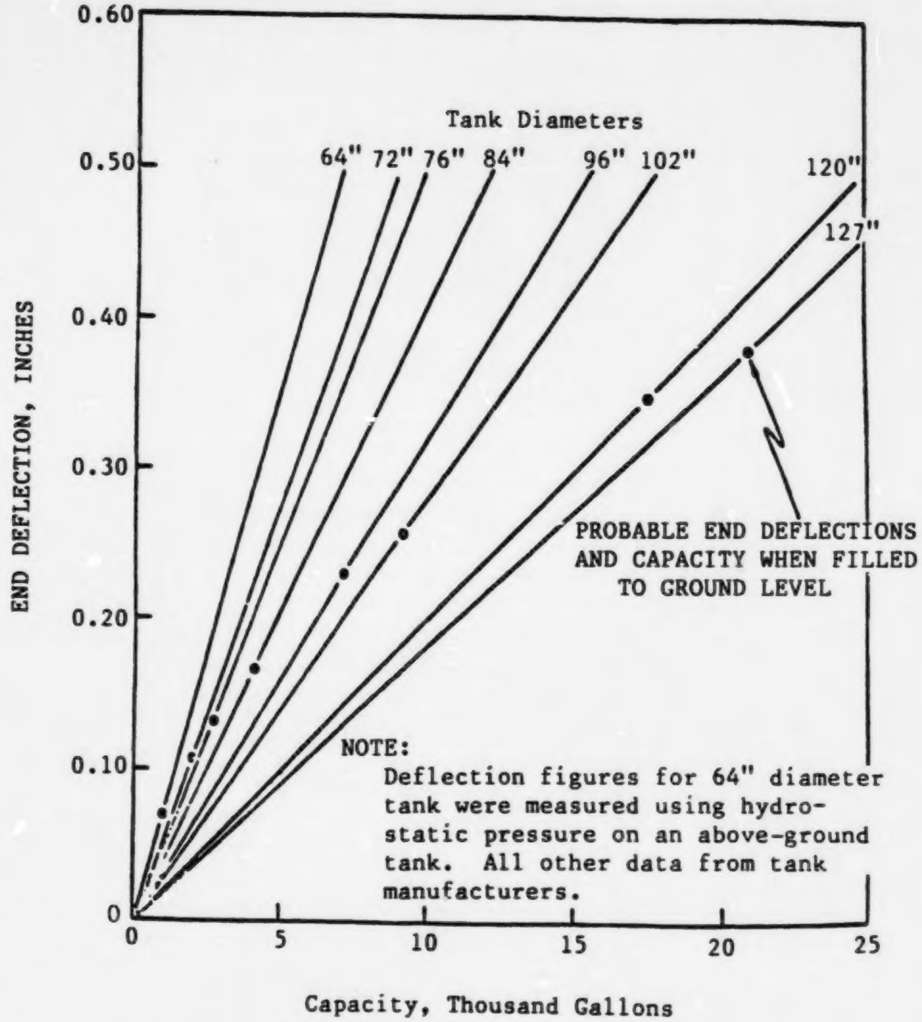

Figure 8. Change in Tank Volume Due To Tank End Deflections - In Gallons (5)

Ref: Hunter Environmental Services, Inc., Leak Lokator LD2000

TABLE 11. PRESSURE-HEIGHT CHART (4), LBS/SQ. IN.

Ref: Heath Consultants, Inc., Petro Tite Tank Tester Bulletin

PRESSURE - HEIGHT CHART

Height	Gasoline	Kerosene	Fuel Oil	Water
1 In.	.026	.029	.031	.036
2 In.	.053	.058	.061	.072
3 In.	.079	.088	.092	.108
4 In.	.105	.117	.123	.144
5 In.	.132	.146	.153	.181
6 In.	.158	.175	.184	.217
7 In.	.188	.209	.219	.258
8 In.	.211	.234	.245	.289
9 In.	.237	.263	.276	.325
10 In.	.264	.292	.307	.361
11 In.	.290	.322	.338	.397
1 Ft.	.316	.351	.368	.433
2 Ft.	.632	.702	.736	.866
3 Ft.	.949	1.053	1.105	1.300
4 Ft.	1.265	1.404	1.473	1.733
5 Ft.	1.581	1.754	1.841	2.166
10 Ft.	3.162	3.509	3.682	4.332
15 Ft.	4.744	5.263	5.523	6.498

	Specific Gravity		API Gravity	
Water	1.00	at 62° F.		Typical
Gasoline	.73		62.3)	gravity
Kerosene	.81		43.2)	readings
Fuel Oil	.85		35.0)	vary with grade and season.

TABLE 12. TOTAL FORCE ON TANK ENDS (4)
FORMULA: FORCE = (AREA) X (PRESSURE) (LBS/SQ. IN.)
TOTAL FORCE IN TONS AT:

Ref: Heath Consultants Inc., Petro Tite Tank Tester Bulletin

Tank Dia.	1 Psi.	2 Psi.	3 Psi.	4 Psi.	5 Psi.
48"	0.9	1.8	2.7	3.6	4.5
64"	1.6	3.2	4.8	6.4	8.0
72"	2.0	4.0	6.0	8.0	10.0
84"	2.8	5.6	8.4	11.2	14.0
96"	3.6	7.2	10.8	14.4	18.0

TABLE 13. APPARENT LOSS OF PRODUCT VOLUME (4) DUE TO FORCE ON TANK ENDS - IN GALLONS

Ref: Heath Consultants, Inc., Petro Tite Tank Tester Bulletin

APPARENT LOSS OF PRODUCT VOLUME DUE TO FORCE
ON TANK ENDS - IN GALLONS
END DEFLECTION IN INCHES

Tank Diameter	1/16	1/8	3/16	1/4	5/16	3/8	7/16	1/2	5/8	3/4	7/8	1	1 1/8	1 1/4	1 1/2
48"	.488	.98	1.47	1.95	2.44	2.93	3.42								
				LINE "A"					LINE "B"						
64"	.872	1.74	2.61	3.48	4.35	5.22	6.10	6.97							
72"	1.101	2.20	3.31	4.41	5.51	6.62	7.72	8.82	11.01						
76"	1.227	2.46	3.68	4.91	6.12	7.36	8.60	9.81	12.27						
84"	1.50	3.00	4.50	6.00	7.50	9.00	10.50	12.00	15.00	18.00	21.00	24.00			
96"	1.957	3.91	5.87	7.82	9.77	11.75	13.70	15.65	19.57	23.50	27.40	31.30			
102"	2.21	4.42	6.63	8.85	11.06	13.30	15.50	17.70	22.20	26.60	31.00	35.40	39.80		
120"	3.06	6.12	9.18	12.25	15.30	18.38	21.40	24.50	30.60	36.70	42.80	49.00	55.12		
126"	3.37	6.75	10.12	13.00	16.85	20.3	23.8	27.0	33.75	40.5	47.2	54.0	60.7	67.50 Steel 5/16"	81.00 Steel 1/4"

"A" Probable Limit of tank end deflection capacity increase

"B" Limit of Maximum tank end deflection capacity increase

Maximum Deflection Figures are Preliminary based on limited data
from Tank Manufacturers and completely fluid soil conditions
Measurements were made with air pressure above ground

Vapor Pockets

Vapor pocket effects may offset the test results obtained via methods which require the tank to be overfilled. This effect increases when rapid changes in ambient pressure or temperature occur during the test period. Basically, three types of vapor pockets are possible: one that forms in the high end of a tank when the tank is not perfectly level, one that is trapped in the top of the manway, and one that is trapped at the top of a drop line (Figure 9) (5). The vapor pocket may release due to a pressure decrease or temperature increase and lead to inaccurate leak test results. Even if the vapor pocket is not released during the test, a change in its temperature or pressure will cause a change in its volume, thus leading to an inaccurate test result. Therefore, vapor pockets should be minimized, without excavations, if feasible. Within a short period of time, vapor pockets trapped in abandoned lines will possibly have a significant effect, especially if vapor pockets are close to grade and are subjected to ambient temperature change. As an example, for a two-cubic-foot vapor pocket at 60 degrees Fahrenheit, a 2.5 degrees Fahrenheit temperature decrease will cause a volume decrease of 0.05 gallons.

Product Evaporation

Evaporation causes a decrease in volume which, if not accounted for, would be interpreted as a leak by the leak measurement device. Awareness of this effect is particularly important in hot weather, dry climates, and high altitudes. The evaporation rate may differ, depending on whether the volume change of the product is measured in or under the fill pipe. The evaporation rate also depends on the volume of the empty space in the tank above the product level. The presence of more empty space above the product level will provide more volume for gasoline evaporation before the space is saturated. For example, in a dry climate at 70 degrees Fahrenheit ambient temperature, for a four-inch fill pipe filled with gasoline, a rate of 0.014 gallons per hour gasoline evaporation can be calculated by Fick's Law of mass transfer. This is equivalent to an 0.3 inches per hour reduction of the gasoline level in the fill pipe.

Piping Leaks

Leaks at tank vents, manholes, or other piping connections to the tank will cause misleading results during the leak detection tests (because in some leak testing methods, this type of leak cannot be differentiated from leaks which occur in the tank).

Tank Geometry

Many of the volumetric leak detection methods are product-level and/or temperature-sensitive. In either case, one or more tank specifications (e.g., the product surface area at different elevations

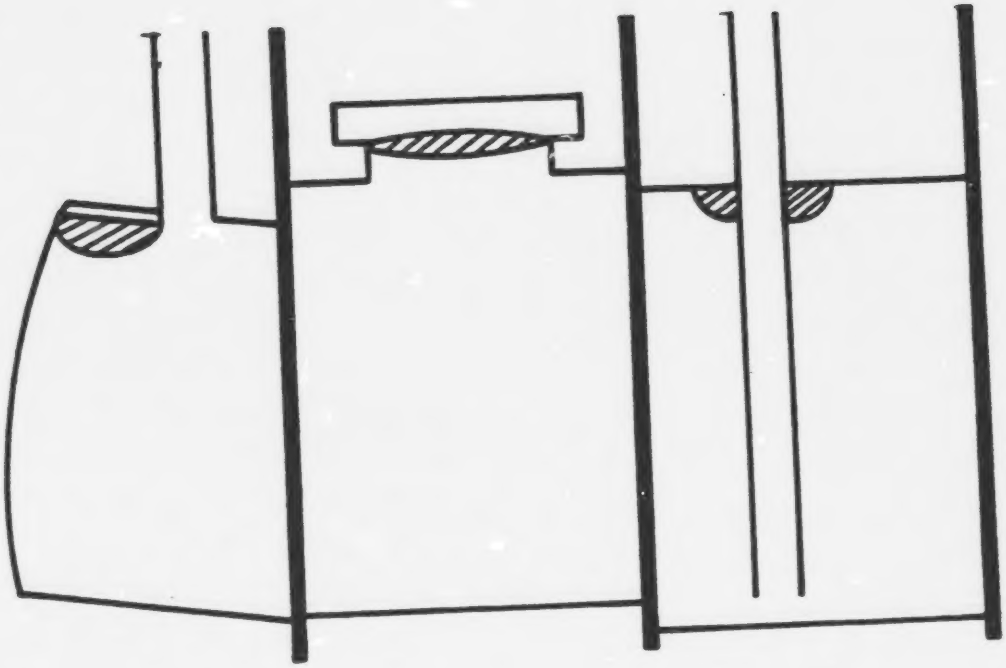

Figure 9. Examples Of Three Common Vapor Pockets (5)

Ref: Hunter Environmental Services, Inc., Leak Lokator LD2000 of the tank or the volume of the tank) is used to calculate the overall volume change and the total volume change due to the temperature change during a test period. In either case, differences between the actual tank specification and the nominal manufacturer's specification can affect the accuracy of test result evaluations.

When a reference tube filled with product is used to measure the representative level changes due to temperature variation, the cylindrical geometry of the tank affects the accuracy of the test results. This effect is minimized when the product level is at 75 percent of a tank diameter, and increased at higher product level (33).

Wind

When a leak detection method is sensitive to product level or pressure changes and the fill pipe or the vents are kept open to the atmosphere during testing, the test results can be affected by wind. Wind, especially when it is strong, can disturb the testing and reduce the data reading accuracy by creating a wave on the product free surface, irregular fluctuation of the pressure exerted on the liquid, or both. The effect is more pronounced when the product level is below the fill pipe.

Vibration

In some leak detection methods, external influences such as ground vibration, traffic, wind, and background noise may cause inaccurate test results. The vibration effect decreases when the testing results are recorded based on a continuous average detection; this can be provided by using a microprocessor. The vibration effect in level measurement increases as the free surface area of the product increases when the test is conducted at product level under the fill pipe. The magnitude of the vibration effect is very difficult to measure precisely. When the test method is based on the product level measurement in the fill pipe, the vibration may be enough to change the overall result from "not leaking" to "leaking" (from slightly below 0.05 gallons per hour to slightly above).

Noise

Noise can affect the testing accuracy of a product level- or sound-sensitive detection method. None of the volumetric leak detection methods are sound-sensitive. In product level-sensitive detection methods, the vibration due to powerful noise such as an explosion or thunderstorm or nearby reciprocating machinery can create waves and reduce the accuracy of the product level measurement. Typical background noise has insignificant effect on the accuracy of nonsound-sensitive detection methods.

Equipment Accuracy

Because changes of variables during a test period are commonly measured, the equipment accuracies reported by most of the manufacturers are the sensitivity of the equipment to respond to certain variation. However, the equipment accuracy (the ratio, multiplied by 100 percent, of error in measurement to actual value) is subject to change at different operating conditions such as temperature, pressure, range of the measurement, etc. If the variations are not compensated for during testing, they can reduce or change the accuracy of the detection method.

Operator Error

The more complicated the testing procedure, the greater the potential for operator error. Typically, this is minimized or reduced by using trained and experienced operators to conduct the testing. In some cases, when the testing requires extensive sealing of the system's ports and openings, improper sealing also could be considered as operator error.

Type of Product

The physical properties of the product (including effects of possible contaminants) could affect the repeatability and/or applicability of a detection method. However, in all the identified leak detection methods in this report, the accuracies are reported to be unaffected by the type of product with physical properties similar to gasoline. These include jet fuel, diesel fuel, and kerosene.

Power Variation

Most of the detection methods require electric power for operation. In some methods, this power is provided by using batteries. Usually, the batteries are replaced with new ones before each testing. This reduces the testing inaccuracy due to power variation. However, when a method uses a 110V AC electric source, the results can be affected by power variations during a test period. This effect can be reduced when both the test results and voltage measurements are printed against a common time base and considered together during the final interpretation.

Instrumentation Limitation

Some of the leak detection methods are applicable to be used and operated under certain tank situations or operating conditions. This can be due to the size and range of applicability of the instruments used in a method. Size of a fill pipe, inclination of the fill pipe, range of product level or pressure change are examples of variables which can limit the applicability of a method. If an attempt is made to use a method outside of its designed range, the accuracy of detection will be decreased.

Atmospheric Pressure

Barometric pressure change during a test period can affect leak rate measurement. For example, in a 10,000-gallon tank filled with gasoline at approximately 60 degrees Fahrenheit (assume constant compressibility factor) with a vapor pocket size of four gallons, a pressure change of 0.02 inches of mercury provides an approximate apparent leak equal to 0.0035 gallons. However, about 80 percent of this volume change is due to the presence of the vapor pocket (because of the difference between the compressibilities of air and gasoline). An apparent leak of approximately 0.01 gallons would result from a change in barometric pressure of 0.07 inches of mercury.

Tank Inclination

When a product level-sensitive detection method is used to determine leaks in an underground storage tank, tank inclination can affect detection accuracy. In an inclined tank, the volume change per unit of level change is different than in a horizontal tank. This is due to the difference between cross sectional areas, at certain product elevations, for inclined and vertical conditions. This effect is corrected by measurement of level change due to a known product volume change.

In some cases, significant inclination may cause the method to be inapplicable.

NONVOLUMETRIC LEAK TESTS

The nonvolumetric leak detection test is used to determine the presence of leaks by qualitative analysis, usually by using a second material other than the product (tracer material). The performance of testing may be affected by certain variables.

Temperature

If a tank must be emptied and then filled with a tracer material (usually helium) prior to leak testing, the temperature effect can change the pressure and the viscosity of the tracer material. The leak rate of tracer material will increase with temperature increase. This is the result of pressure increase and viscosity decrease of a tracer material due to temperature increase, both of which tend to increase the leak rate. However, because the typical tracer material is helium with significant diffusivity, the temperature increase can only reduce the detection time of the tracer slightly. Therefore, the accuracy of this test is not significantly affected by temperature changes.

Some detection methods, in addition to detection of leaks by tracer gas, attempt to provide an approximate leak rate by pressure monitoring during a test period. These methods must compensate for pressure change due to temperature effect.

If testing is conducted with product at normal existing conditions and leaks are detected by monitoring the sound due to leaks or detection of tracer gas outside a tank, the change of the leak rates due to temperature change will have slight effect on the detection time and no effect on the testing accuracy.

The change of the temperature would be based on ambient temperature change, sunshine, clouds, rain, water table, and type and compaction of backfill material.

Water Table

If a detection method indicates a leak by detection of tracer gas outside of a tank, the presence of a high water table can prevent the exit of the tracer gas from the tank. However, this can be overcome by increasing the pressure of the tracer material inside the tank until it exceeds the external pressure, in which case the tracer gas (helium) will bubble up through the water to the surface. For certain pressure of tracer material inside the tank, a higher water table will result in a longer detection period.

Some detection methods, in addition to the detection of leaks by sniffing tracer gas outside a tank, attempt to provide maximum possible product leak rate by pressure monitoring inside the tank. In this case, a partial masking effect of the water table affects the testing accuracy for leak rate evaluation.

When a method is applied to detect leaks by sound monitoring of the leak under pressurized or vacuumed tank conditions, a lower partial masking effect (lower water tables) can cause a more pronounced sound for detection of a leak. In this case, due to the pressure differential at two sides of a leak opening, a complete masking effect is avoided.

Tank Deformation

The nonvolumetric methods operate either by monitoring a tracer gas outside a tank or monitoring the sound due to a leak inside a tank. Therefore, tank deformation does not affect the detection accuracy. (However, the effect of the tank deformation on the diameter of small-size leaks should be studied.)

When a method provides the maximum possible leak rate of the product by pressure monitoring inside a tank, the tank end deflection effect on the leak rate will decrease for longer test periods.

Vapor Pocket

In nonvolumetric detection methods it is necessary to test a tank at emptied or normal existing product level condition. Therefore, during these testings, vapor pockets cannot be created.

Product Evaporation

When testing is conducted on a completely empty tank, the product evaporation effect is eliminated. If a nonvolumetric method indicates leaks by detection of a tracer gas outside a tank or sound monitoring of leaks inside a tank, in both cases at normal existing product level, the product evaporation cannot affect testing performance.

Piping Leaks

In nonvolumetric tank leak testing with tracer gas, leaks at tank vents, manholes, or other piping connections to the tank can cause misleading results. This is because the tracer gas is very diffusive and can diffuse through some pipe connections even after they are tightened enough to contain liquids.

Tank Geometry

None of the nonvolumetric leak detection methods is product level-sensitive. Therefore, tank geometry does not affect testing.

Wind

Based on the testing procedures for nonvolumetric detection methods, all the ports of a tank should be sealed from the atmosphere prior to testing to assure that the wind does not affect the testing performance. However, in some detection methods where leak detection is performed by sniffing a tracer gas at the ground level above a tank, in windy conditions, small monitoring holes should be installed. This will prevent the masking effect of wind for detection of tracer gas by direct sniffing of gas through monitoring holes.

Vibration

None of the nonvolumetric detection methods are sensitive to the level change of any fluid during a testing period. Therefore, the testing performance is not affected by the vibration effect.

Noise

Noise can affect the testing accuracy of a sound-sensitive detection method. Unless the background noise can be differentiated from the sound due to leaks, the test cannot be successfully carried out.

Equipment Accuracy

(See the description for volumetric leak detection methods.)

Operator Error

In all nonvolumetric methods, all tank ports must be sealed from the atmosphere. Therefore, one of the major potentials for operator error is the operator's ability to seal a tank completely prior to a test. In sound-sensitive detection methods, the operator's level of experience can reduce the time required to assure the certainty of detecting leaks or the leak rate.

Type of Product

When testing is performed in an empty tank, the effect due to type of the product will be completely eliminated. In acoustical leak detection methods which are conducted in tanks containing product, the product viscosity can affect the sound characteristics of leaks below the product level. However, for products with properties similar to liquid petroleum fuel, this effect is insignificant.

Power Variation

The nonvolumetric leak detection methods are based either on detection of a tracer gas (helium) outside the tank or detection of the leak sound inside a tank. In either case, the typical AC power variation during the detection period cannot be enough to mask the detection completely.

Instrumentation Limitation

(See the description for volumetric leak detection methods.)

Atmospheric Pressure

Because all the nonvolumetric detection methods are operated only after the tank ports are sealed to the atmosphere, atmospheric pressure (barometric pressure) change has no effect on the test results.

Tank Inclination

Because none of the nonvolumetric leak detection methods are product-level sensitive, tank inclination does not affect testing.

General Problems

The principal problems inherent in nonvolumetric detection methods are that they:

- Cause or enhance a leak during testing by exerting pressure higher than normal tank operating pressure.
- Adversely affect product quality if a compound that is not inert is used for testing in a tank containing product.
- Risk an explosion hazard when product is present in the tank during testing.
- Usually cannot measure leak rate accurately, or at all.
- Require a long testing time for low leak rates when the type and compaction of the backfill material around the storage tank is varied. In some cases, the testing time could be up to 24 hours.

INVENTORY CONTROL

The problem of keeping records of product inventory is complicated by the fact that gasoline is volatile and losses due to evaporation are, to a degree, unavoidable. However, the inventory method could be used as a first and most convenient method for gross leak monitoring. The accuracy of this method is very much related to the manner in which variable factors are compensated.

LEAK EFFECTS MONITORING

Problems associated with methods in this category are not discussed in this section because these methods are not considered as existing or developing in-tank, leak detection techniques, which are the focus of the present study.

SECTION 6

LEAK DETECTION METHODS REVIEW

All leak detection methods discussed are reviewed in this section. The classifications of leak detection methods are presented first, and then the methods themselves are described. Tables 1 through 9 (in Section 2) summarize the general information and operational capabilities for each of the leak detection methods discussed in this report.

Note that each "Manufacturer's Description of Method" is based on the available literature from the manufacturer of that method. However, the information regarding the "Manufacturer's Techniques to Compensate for Effects of Variables" is a combination of the available information in the manufacturer's literature, reports, and/or verbal communications with the staff of the manufacturer.

The "Engineering Comments" herein are based on the authors' engineering judgment. Therefore, it is possible an engineering judgment would be different from the information or detection method capabilities claimed by the manufacturer.

As used in this section, "testing" refers to those leak detection methods that determine, at a point in time, whether a tank or tank piping is tight or leaking. Testing is different than monitoring techniques. Monitoring techniques provide continuous surveillance to detect early leaks or area-wide surveillance to investigate the source of a leak or spill. "Tank testing" refers to the detection of leaks in tanks and tank piping systems.

CLASSIFICATION

The four general classes of methods to detect leaks in underground storage tanks are:

- Volumetric (quantitative) leak testing, for leak indication and leak rate measurement

- Nonvolumetric (qualitative) leak testing, for leak indication

- Inventory control

- Leak effects monitoring.

These methods can be used individually or in combination.

Volumetric (Quantitative) Leak Testing

This classification of testing includes methods which test for leaks based on the volume change. The change in volume can be determined by measuring parameters associated with volume change; including changes in liquid level, temperature, pressure, and density.

Nonvolumetric (Qualitative) Leak Testing

This classification of testing includes methods which principally determine the presence of a leak in an underground storage tank by qualitative measurements. After identifying an underground tank leak by this technique, a volumetric test can be used to measure the leak rate.

The main concerns about most qualitative testing methods are: potential enhancement of leak, effect on product quality, explosion hazard, inability to measure the leak rate, and required time for testing.

Inventory Control

Advocates of inventory control claim it is the simplest and most economical leak detection method. They contend that the technique has not worked in the past only because recommended practices have not been followed. Recommended practices for inventory control at service stations can be found in the American Petroleum Institute's Publication API 1621, Recommended Practice for Bulk Liquid Stock Control at Retail Outlets (55).

Leak Effects Monitoring

This classification of leak detection methods identifies leaks by monitoring the environmental effects of the leak inside or outside an underground storage tank. These methods usually require drilling small holes or wells, installing monitoring casings, and chemical analysis.

LEAK DETECTION TESTING METHODS

Volumetric (Quantitative) Leak Testing Methods

1- Ainlay Tank Tegrity Testing (TTT) (6,7)--

Manufacturer's Description of Method (6)--In this method, the level change in a completely filled tank is measured by monitoring pressure change through a bubbling system (Figure 10). The method is used to measure and differentiate leaks in tank and piping. The tank is filled into the fill pipe the evening before testing.

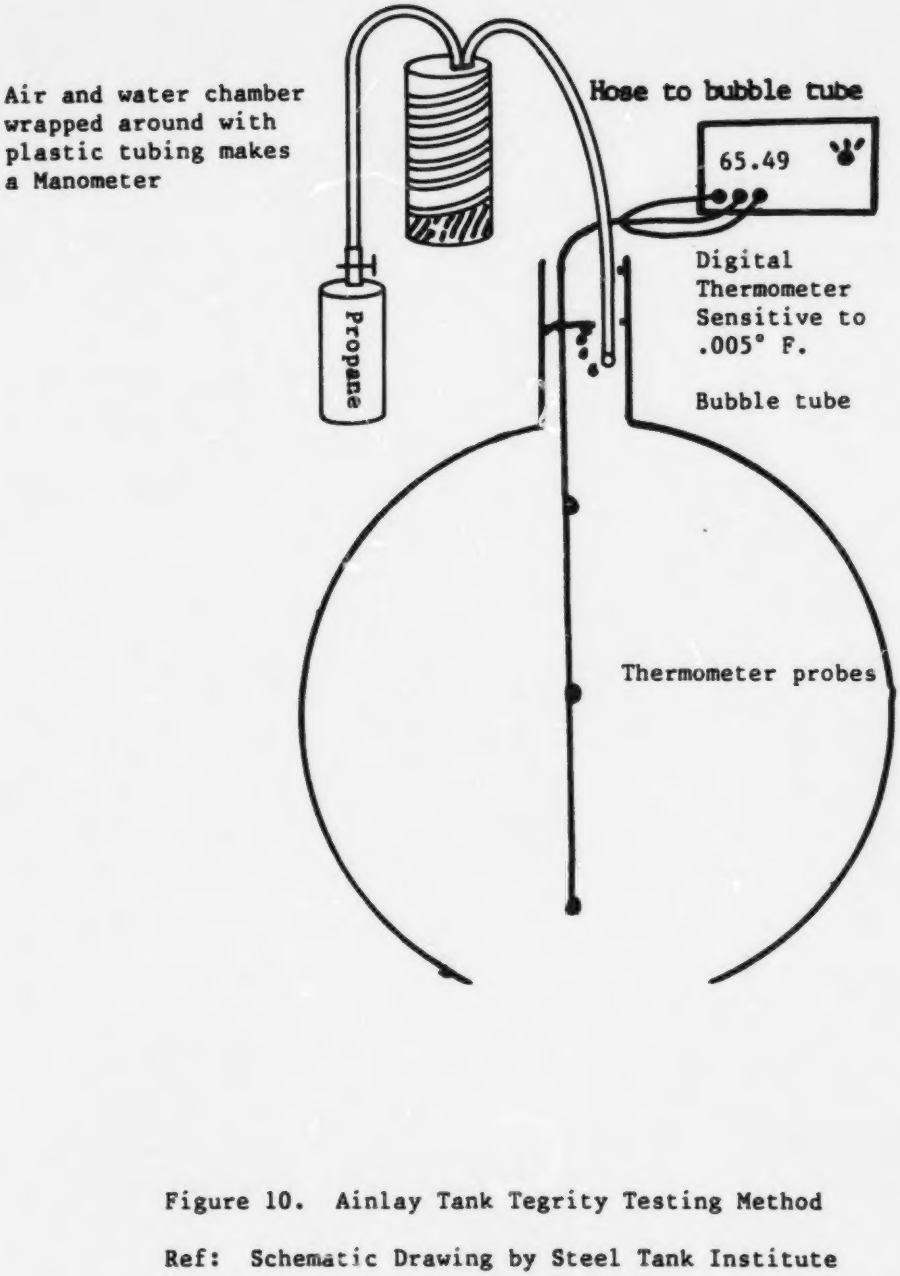
Air and water chamber wrapped around with plastic tubing makes a Manometer
Hose to bubble tube
65.49
Propane
Digital Thermometer Sensitive to .005° F.
Bubble tube
Thermometer probes

Figure 10. Ainlay Tank Tegrity Testing Method

Ref: Schematic Drawing by Steel Tank Institute

Propane gas bubbles are introduced one inch below the product level through a 1/4-inch copper tube. The pressure required to introduce bubbles varies with changes in product level, and is related to volume changes. Pressure changes are monitored by a manometer type coil (slope tube) with a colored water indicator. A slight drop in liquid in the tank is exaggerated approximately 50 times when transmitted from bubble tube to the slope tube. The temperature change during the test period is measured. Based on data available at the site on tank volume, the volume change due to temperature change during a test period is calculated. Finally, the volume change due to a leak is calculated by subtracting the volume change due to temperature change from the total volume change.

Ainlay TTT can be performed in one hour and can detect a leak as small as 0.02 gallons per hour. The equipment used for setup and operations is carried in a portable case and can be hand carried as baggage on board an airplane.

Manufacturer's Techniques to Compensate for Effects of Variables (7)--In the Ainlay TTT detection method, the following effects of variables are compensated for as described below:

- Temperature--Temperature change is measured by three electronic temperature probes at the center of each of three product layers with 25 percent, 50 percent, and 25 percent, respectively, of tank volume. Locations of the probes for tanks with various diameters are provided on a table. When the three temperature readings have stabilized, the temperature reading is recorded and averaged on the report form. The temperature can be read on a digital display with 0.01 degrees Fahrenheit accuracy.

  The API gravity of the product is measured at the beginning of the test with a hydrometer. A table is included in the instruction book. For testing a tank, this table will translate the API gravity reading to coefficient of expansion. This table covers all petroleum products from fuel oil to highest API gasoline. Since the coefficient of expansion of chemical solvents cannot be determined by hydrometer, another table is included to cover 175 chemicals such as alcohol, acetones, etc.

  If the tank tested has a drop tube (an insert in the fill pipe which extends nearly to the bottom of the tank), it must be removed before the test because the tube affects accuracy in the detection of temperature shifts. In addition, filling and allowing the tank to stand overnight stabilizes the temperature in advance of the test.

- Water Table--The presence and amount of water in the tank is determined with water-finding paste on the depth level stick at the beginning and completion of the test. An increase or decrease in the water level will indicate a leak into or out of the tank.

- Tank Deformation--This effect is minimized by filling the tank the evening before testing (8). However, if the tank is topped off one hour before the test, the end deflection effect is recognized when the calculated leak rates change in a decreasing manner. As long as the end deflection is recognized and the measured volume changes are not correlated with changes caused by temperature change, the calculated leak rate is not considered as TTT's final result. Therefore, the overall testing time will increase.

- Vapor Pockets--If vapor pockets are noticeable, the suspected locations are excavated and the vapor pocket is released (8). (For example, the vapor pocket at the end of the tank is released by drilling a hole at that end.) As a second alternative, the test is conducted when the level of the product is 0.5 inches under the fill pipe.

- Product Evaporation--Propane gas is bubbled into the tank to reduce the evaporation due to bubbling of gas in the product.

- Piping Leaks--A leak in the piping system can be detected by lowering the product level to about one inch into the fill pipe, or one inch above the top of the tank. This places the product level below the piping level. If a leak is indicated at this level, it must be in the tank as lines are not involved in the test.

- Equipment Accuracy--Digital temperature probes register and read out temperature shifts as small as 0.01 degrees Fahrenheit. The volume change of approximately less than 0.01 gallons can be observed on the manometer (slope tube).

- Operator Error--As operator skill increases, the temperature reading can be as precise as 0.005 degrees Fahrenheit. In addition, a better estimation of a portion of a 0.01-gallon volume change can be provided.

- Type of Product--As long as a bubble can be generated in the product, the accuracy of the TTT method does not change (8).

- Tank Inclination--This effect can be corrected by measuring the exact product volume change in the coil-type manometer with change in product level in the fill pipe. This is done by addition/removal of the product, with known volume, to/from the fill pipe until the product level in the slope tube reaches the level when the test began.

- Tank geometry, noise, power variation, and atmospheric pressure do not have an effect on testing accuracy (8).

Engineering Comments--The Ainlay TTT's accuracy may be affected for the following reasons:

- Differences between measured temperature changes and actual temperature changes.
- Lack of compensation for masking effect on the leak rate caused by hydrostatic pressure and surface tension.
- Presence of unidentified vapor pockets.
- Evaporation of product during a test.
- Difference between the obtained tank volume and the actual volume.
- Strong wind.
- Strong vibration.
- Slope tube limitation to measure volume change more than 0.06 gallons during the test.
- Effect of barometric change on vapor pocket volume (if any).

In addition to the above, another disadvantage of this method is that a printed readout is not provided for studying unusual events during a test.

2- ARCO HTC Underground Tank Leak Detector (7,9,10,11,12)--

Manufacturer's Description of Method (7,12)--The ARCO underground tank leak detector is an ultrasensitive device for measuring volume changes in an underground storage tank caused by leaks through tank walls under a product level, or product distribution lines (Figure 11). This method is substantially unaffected by temperature changes that may occur in the tank during a test. However, a one-hour waiting period is recommended to allow the equipment to stabilize and wave action to diminish. To minimize fuel evaporation during the test period, a saturated vapor condition is provided above the liquid phase. This is done by circulating the fuel in the tank for an amount of time, set by tank size.

The ARCO system consists of a float, a detector rod, and a strip chart recorder. The float senses the liquid level in the tank, the detector rod measures the relative position of the float with respect to the rod, and the recorder makes a permanent record of the measurement. Figure 11 illustrates the arrangement of testing equipment in a tank.

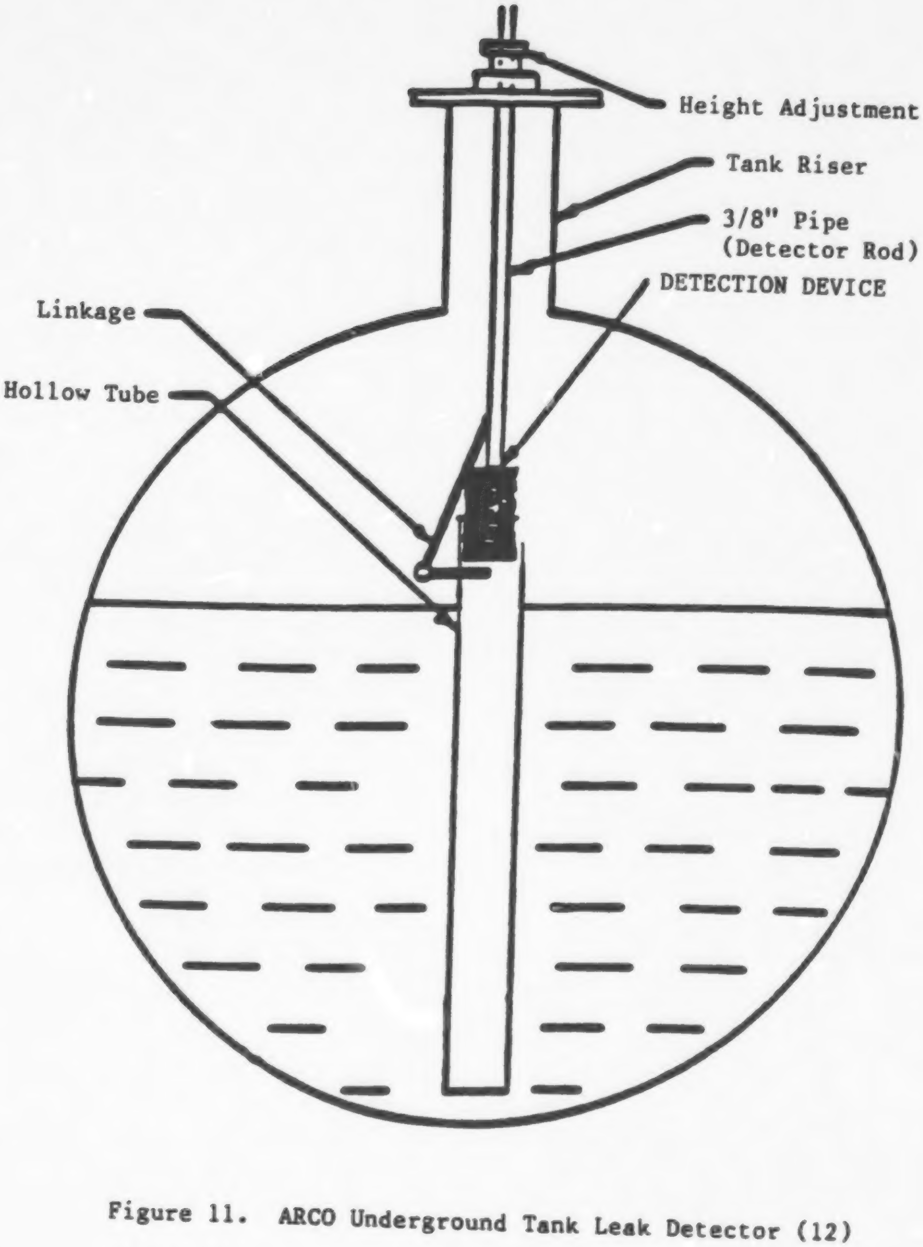
Height Adjustment
Tank Riser
3/8" Pipe
(Detector Rod)
DETECTION DEVICE
Linkage
Hollow Tube

Figure 11. ARCO Underground Tank Leak Detector (12)

Ref: ARCO Underground Tank Leak Detector Bulletin

The float is assembled differently for different tank types. A float shell is selected from a group of varying length shells suitable for a variety of tank sizes. The float length and weight are chosen based on the tank diameter, the liquid height in the tank, and the liquid density. These measurements are taken at the site just prior to starting the test.

The detector rod assembly consists of a photoelectric cell and a float attachment hinge. The float movement forces an ink-type solution into or out of the photocell. The change in light transmittance in the photocell results in a voltage drop across the cell. The voltage change, which is a function of the product level change, is measured by a precalibrated voltage meter. Calibration and one-hour testing periods are continued until two consecutive readings give the same calculated result. The strip chart recorder has multiple input ranges. The ARCO system can test four tanks simultaneously.

The test can be performed accurately when the tank level is between 66 and 76 percent of the tank diameter (9). Only leaks under the product level may be detected.

The ARCO leak detector can be used with the tank at a normal operating level and pressure. The entire test procedure takes two to three hours and leaks smaller than 0.05 gallons per hour can be detected; however, longer test periods are possible. Operator attendance is not required during each one-hour test interval.

Manufacturer's Techniques to Compensate for Effects of Variables (7,12)--In the ARCO Tank Leak Detection testing methods, the following effects of variables are compensated as described below:

- Temperature--The detector takes advantage of natural temperature compensation by selecting a point in the tank (when the product level in the tank is less than 76 percent of tank diameter) where a floating object will be unaffected by temperature variations in the liquid. A relationship exists between temperature and three factors; namely, liquid density, liquid buoyant forces (a function of density), and liquid volume. A change in temperature, affecting liquid volume, can be exactly offset by density (buoyancy) changes, providing the floating object is at the point where the volumetric and density changes caused by temperature variation have an equal, neutralizing effect.

- Water Table--Water ingress will be detected as an upward float movement, thus the ARCO system detects "leaks in" as well as "leaks out."

- Tank Deformation--Because the tank is not overfilled during the test, no provision needs to be made for this effect.

- Vapor Pockets--Vapor pockets are not formed in this test (because the tank is not filled).

- Evaporation--Based on field observation, this method reduces product evaporation during the test period by providing a saturated vapor condition above the liquid phase. This is done by circulating the product in the tank for a required period before conducting the test.

- Piping Leaks--When the tank testing is complete, the submerged pump (which is part of the tank system) is turned on, and the dispenser is kept in the off position; therefore, leaks in the lines are measured with this method.

- Tank Geometry--In a horizontal cylindrical tank, the thermal effect on level change is minimized when the product level is as described in the test procedure (13).

- Equipment Accuracy--The system is calibrated for readout for level change due to one liter volume change at the beginning of each one-hour test.

- Operator Error--The operator error will be reduced with training, experience, and follow-up of the testing procedure (12).

- Type of Product--The method could be used with any type of liquid as long as the float can move freely (12).

- Tank Inclination--The effect due to this variable is compensated by using a calibration at the beginning of each one-hour test.

- Noise, power variation, and instrumentation limitation will not affect the testing accuracy (12).

Engineering Comments--The accuracy of the testing may be affected for the following reasons:

- Existence and change in the water level at the bottom of the tank. This prevents a constant buoyancy force during the test period. In addition, leak rate reduction or masking due to ground water cannot be avoided.

- Occurrence of waves on the product's free surface due to wind and vibration. However, this effect is partially corrected by the chart results evaluation.

- Power variations.

- Atmospheric pressure change during the test period.

In addition, one of the disadvantages of this method is that tank leaks above the product level will be undetected.

3- Certi-Tec Testing (10,14)--

Manufacturer's Description of Method (14,15)--The Certi-Tec test monitors pressure changes resulting from product level changes (Figure 12). Product level changes are due to volume changes. The method is capable of testing storage tanks filled either beyond or below capacity.

The system uses a sensitive pressure transducer located below the product surface. Five or more temperature sensors are used to measure temperature at different levels. A microprocessor collects temperature and pressure change data and determines the volume change of the mass above the pressure transducer.

When it is possible to fill the tank, the test method uses a standpipe. The standpipe is installed above the grade of the tank. The pressure transducer is installed in the standpipe and the product level change is measured. If a leak is detected, the product level is decreased below the fill pipe and the pressure transducer installed in the tank. The results of the tests at these conditions could determine if the leak is in the tank or piping.

The system accuracy to measure leak rate is within that recommended by NFPA (0.05 gallons per hour). The accuracy of the test is reduced when a partially filled tank is tested. However, to achieve maximum accuracy, the test must be performed over a longer period of time than the test with the standpipe. The test can be performed in two- to four-hour testing periods.

Manufacturer's Techniques to Compensate for Effects of Variables (15)
--In the Certi-Tec Tank testing method, the effects of the following variables are compensated as described below:

- Temperature--In this system, temperature sensors are suspended at five or more levels. A microprocessor collects the temperature data to measure the volumetric average of product temperature during a test. The volume change of the mass above a pressure transducer, which is used for leak detection, is determined for the estimated temperature change (10,14).

- Water Table--A potential problem exists when the test is conducted in a tank filled with less than capacity and the tank is located in high ground water conditions. The ground water could mask the leak. In this testing, the level of water in the tank is measured by water-finding paste.

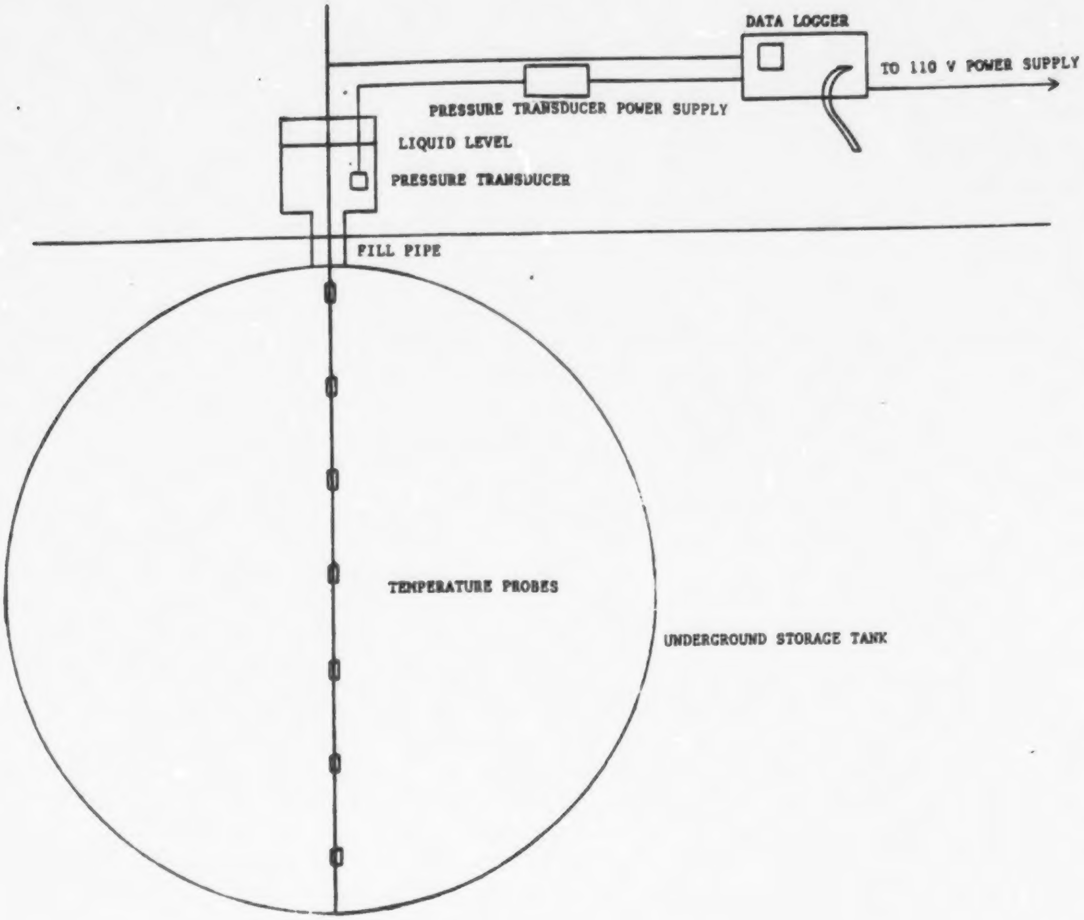
DATA LOGGER
TO 110 V POWER SUPPLY
PRESSURE TRANSDUCER POWER SUPPLY
LIQUID LEVEL
PRESSURE TRANSDUCER
FILL PIPE
TEMPERATURE PROBES
UNDERGROUND STORAGE TANK

Figure 12. Certi-Tec Tank Testing System (14)

Ref: Schematic Drawing by Fuel Recovery Co.

- Tank Deformation--This effect is recognized when the measured leak rate changes in a decreasing manner.

- Vapor Pockets--When a tank can be filled, a test is conducted with standpipe. In this case, the head pressure induced by the standpipe can reduce the vapor pocket volume (if any) and, therefore, reduce the volume change due to vapor pocket effect. When the test is conducted with product level under the fill pipe, no vapor pocket exists to affect the testing accuracy; however, this reduces the pressure transducer sensitivity and increases the time for testing.

- Equipment Accuracy--The temperature readout of smaller than 0.01 degrees Fahrenheit can be recorded. In addition, the pressure transducer can provide ±0.25 percent accuracy and ±0.05 percent repeatability.

- Operator Error--Operator error will be minimized if the testing procedure is followed precisely.

- Type of Product--The system could be used with gasoline, jet fuel, diesel fuel, and other liquid petroleum fuels.

- Instrument Limitation--The pressure transducer can only be used from 0 to 3 pounds per square inch pressure range.

- Atmospheric Pressure--The system is designed to compensate for atmospheric pressure change during the test period. This is accomplished by measurement of the gage pressure.

- Noise and power variations will not affect the test results.

Engineering Comments--The accuracy of the Certi-Tec testing can be affected by:

- Difference between measured temperature changes and actual temperature changes.

- Lack of compensation for water table masking effect or reduction of the leak rate.

- Vapor pockets, if the test is conducted using the standpipe.

- Product evaporation when the test is conducted without standpipe.

- Difference of obtained tank volume with the actual volume.

- Wind, especially when the test is conducted at product level below the fill pipe. However, it is partially corrected by the microprocessor, which continuously provides the average results for every 15 seconds.

- Vibration, especially when the test is conducted at product level below the fill pipe. However, it is partially corrected with the same technique to compensate for wind.

- Equipment accuracy should be checked for each test by calibration.

- Power variations.

- Effect of atmospheric pressure change on vapor pockets volume (if any).

- When the test is conducted with a pressure transducer in the fill pipe or tank, the tank inclination effect should be compensated by calibration.

4-"Ethyl" Tank Sentry Testing (7,9,10,11,16)--

Manufacturer's Description of Method (16)--The "Ethyl" tank sentry is used to detect and measure small changes in the liquid level of underground fuel tanks. The heart of the detector is a "J" tube manometer containing a special indicator fluid; the fluid is not miscible with fuel. The long leg of the "J" tube connects with a larger diameter fuel reservoir. A manually operated valve on the long leg of the "J" tube is used to admit or drain fuel from the reservoir. A second valve is installed in the short leg of the "J" tube to control the indicator fluid. Both valves can be operated while the detector is in the tank. Figures 13 and 14 illustrate the detector kit and the installation of the detector in a tank (16).

The operating principle during the test is that a change in the indicator fluid level occurs due to a change in the liquid level of a partially filled tank. Any change in tank level is magnified by a factor of approximately five in the manometer. The difference in height of the indicator fluid in the manometer legs is read and recorded. By referring to tank tables and applying certain factors, the loss or gain in fuel volume is calculated. A level change as small as 0.02 inches can be detected. For a one-hour test with the product level in the middle of a typical, cylindrical 8,000-gallon tank (eight-foot diameter), a change of 0.02 inches per hour reflects a leak rate of 2.12 gallons per hour. Because the accuracy in measuring and detecting leaks is a function of the time span of the test, the probability of detection can be increased by extending the test time or by averaging two or more replicated tests. As an example, a level change of 0.02 inches within a ten-hour span (instead of a one-hour span) calculates to a 0.212 gallons

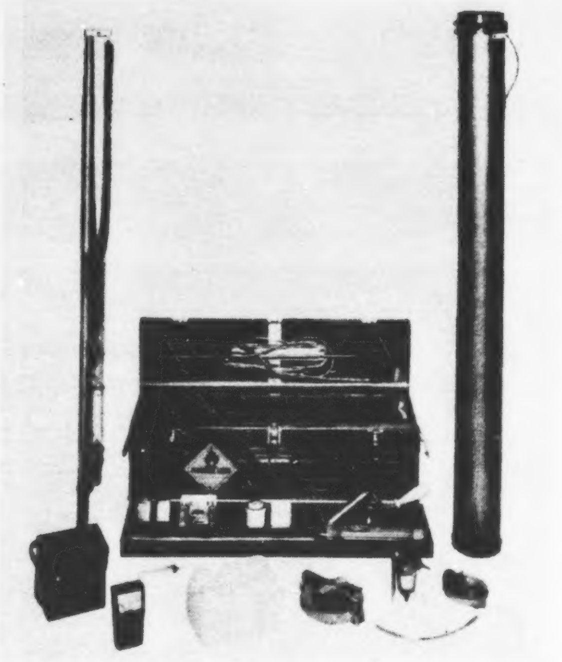

Figure 13. "Ethyl" Tank Sentry Kit (16)

Ref: Ethyl Corporation Bulletin

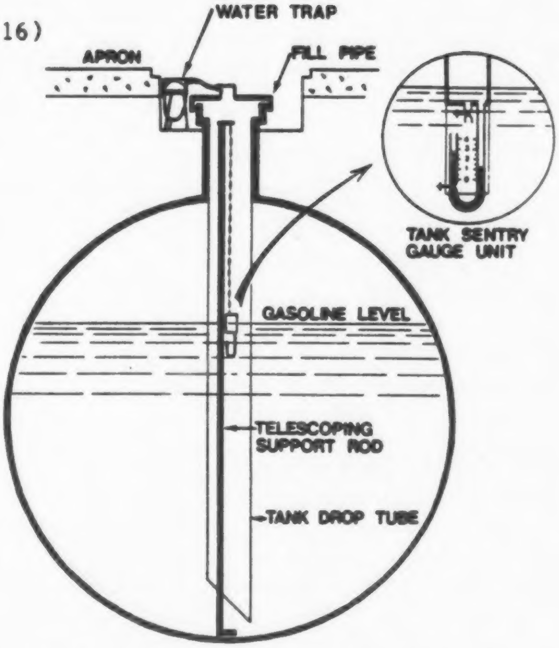
WATER TRAP
APRON
FILL PIPE
TANK SENTRY GAUGE UNIT
GASOLINE LEVEL
TELESCOPING SUPPORT ROD
TANK DROP TUBE

Figure 14. "Ethyl" Tank Sentry Installation (16)

Ref: Ethyl Corporation Bulletin

per hour leak rate. The test requires that the test period must span several hours.

Manufacturer's Techniques to Compensate for Effects of Variables (17) --In the "Ethyl" Tank Sentry testing, the following effects of variables are compensated as described below:

- Temperature--The temperature is measured by a temperature probe (thermometer). This is done before and after the tests and is used to calculate the volume change due to temperature effect. Equipment instructions state that a one degree Fahrenheit change in product temperature during the test will negate the results; tests should not be conducted within 24 hours after product delivery. After this time, the product temperature usually varies less than one degree Fahrenheit for the test period. In addition, careful adherence to the test procedure reduces possible effects of temperature variables (16).

- Tank Deformation--This effect is eliminated during the testing period. This is due to the test requirement that the tank be idle and no deliveries be made to the tank during the preceding 24 hours. In addition, careful adherence to the test procedure reduces possible effects of tank end deflection variable (16).

- Vapor Pockets--Because the testing requires product level under the fill pipe, this effect is eliminated

- Noise--Not applicable.

- Equipment Accuracy--Any change in tank level is magnified in the manometer, making it possible to detect level changes as small as 0.02 inches.

- Operator Error--This can be minimized by carefully following the testing procedure.

- Type of Product--The testing accuracy would be unaffected by the product type as long as the viscosities and vapor pressures of products are not too high. However, "Ethyl" Tank Sentry may or may not give accurate readings with gasolines that contain any oxygenates (alcohol).

- Power Variation--Not applicable.

- Instrumentation Limitation--The method is used to measure leaks in underground fuel tanks having a three-inch or larger fill pipe diameter and containing at least 20 inches of fuel (16).

- Atmospheric Pressure--The manometer eliminates the effect of barometric changes during the testing period.

Engineering Comments--The "Ethyl" tank sentry testing accuracy may be reduced due to the following reasons:

- Difference between measured temperature changes and actual temperature changes.
- Lack of compensation for water table level on the leak rate. In addition, it is not capable of preventing masking effect due to the water table. However, the effect is reduced when a test is conducted for a longer period of time.
- Product evaporation during the test period due to the temperature and/or pressure change.
- Piping leaks.
- Difference in the calculated surface area and volume of the product, based on the available tank's data, and the actual values to estimate the overall volume change and thermal volume change during a test period.
- Tank inclination is not considered or compensated by calibration.

In addition, the system disadvantages include:

- The data are not recorded continuously. They are only recorded at the beginning and end of the test period.
- The leaks are not detected above the product level in the storage tank.
- Long testing period is required to differentiate between tank leaks and piping leaks. Therefore, usually another method of leak detection is required for pipe testing.

5- EZY-CHEK Leak Detector (5,7,10,11,18,19)--

Manufacturer's Description of Method (5,18,19)--In this method, the level change is measured by monitoring the pressure change through a bubbling system. The storage tank is typically overfilled into the fill pipe. However, the testing can be taken at any level in the standpipe above the highest point in the tank, in the fill pipe, or in the tank.

The system consists of a standpipe, an averaging temperature probe, an air supply tank and chart recorder. The liquid level change is monitored with a sensitive pressure gage. The pressure recorder has a

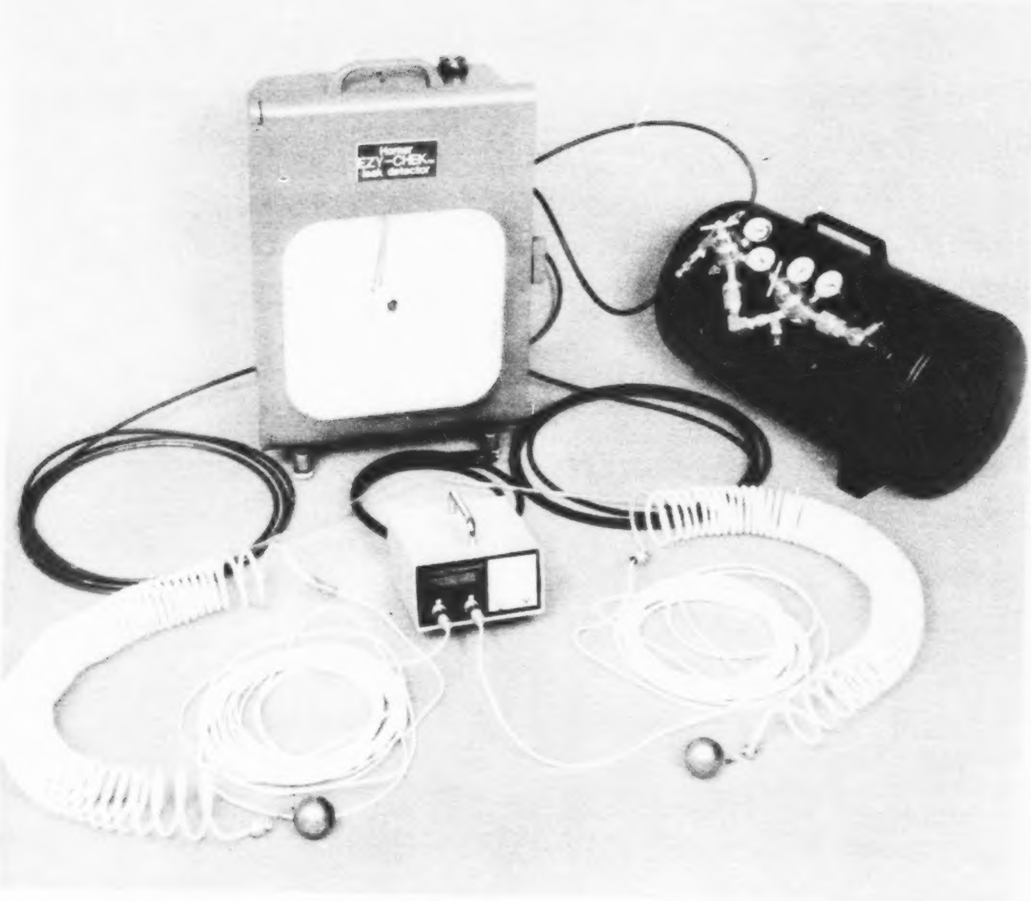
Horner
EZY-CHEK
leak detector

Figure 15. Ezy-CHEK Leak Detector (18)

Ref: Horner Creative Metals Bulletin

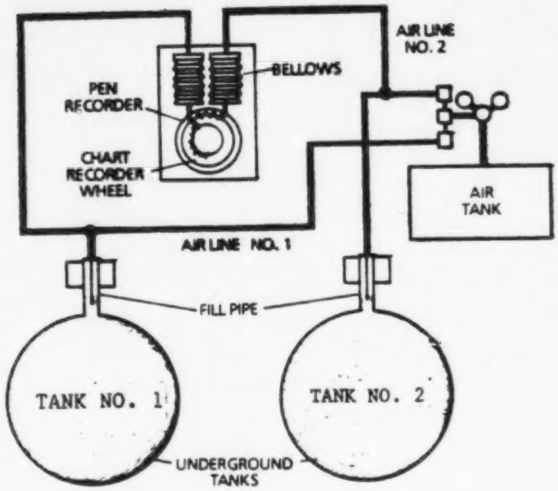
AIR LINE NO. 2
BELLOWS
PEN RECORDER
CHART RECORDER WHEEL
AIR TANK
AIR LINE NO. 1
FILL PIPE
TANK NO. 1
TANK NO. 2
UNDERGROUND TANKS

Figure 16. EZY-CHEK Leak Detector Installation (18)

Ref: Horner Creative Metals Bulletin

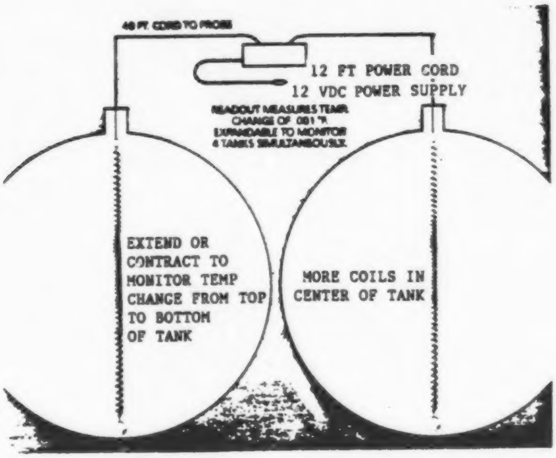
40 FT. CORD TO PROBE
12 FT POWER CORD
12 VDC POWER SUPPLY
READOUT MEASURES TEMP. CHANGE OF .001 °F. EXPANDABLE TO MONITOR 4 TANKS SIMULTANEOUSLY.
EXTEND OR CONTRACT TO MONITOR TEMP CHANGE FROM TOP TO BOTTOM OF TANK
MORE COILS IN CENTER OF TANK

Figure 17. EZY-CHEK Leak Detector Temperature Averaging Probe (18)

Ref: Horner Creative Metals Bulletin

full range of approximately one ounce of pressure. The air supply forces a small flow of low pressure air into the top 1/2 inch of liquid in the tank, through a 1/4-inch tube clamped to the fill pipe. The recorder measures the pressure necessary to cause the bubbling action. If the recorder charts a straight line, the liquid level is not changing. The temperature change is monitored with an averaging temperature probe to compensate for the volume change due to the temperature variation during the testing period. Figures 15 through 17 illustrate the equipment and the installation of the EZY-CHEK system (18).

Complete tank testing includes at least four 15-minute testing periods and could usually be performed with 0.01 gallons per hour leak detection accuracy within four hours after the tank is topped off.

Manufacturer's Techniques to Compensate for Effects of Variables (5,18,19)--In the EZY-CHEK testing method, the following effects of variables are compensated as described below:

- Temperature--Temperature change is monitored by an electronic temperature averaging probe which is installed in the tank. The probe consists of platinum sensing wires encased in a "coil spring" of special plastic tubing. The probe is formed with more coils at the center of its length than at its ends, thus proportioning the length of sensing wire to the volume of the tank. When the weighted probe is dropped into any tank ranging from 2 to 20 feet in diameter, it stretches to match the tank diameter. The digital readout display temperature changes to 0.001 degrees Fahrenheit. It can monitor up to four tanks simultaneously. Currently, the above temperature measurement system is used instead of the system with "stoddard solvent," which was used in the past.

- Water Table--When a high water table is suspected, a standpipe device can provide the necessary head pressure to prevent the masking effect. In this situation, the volume change is measured in the standpipe.

- Tank Deformation--If it is necessary to stabilize tank end deflections, a standpipe device can provide the necessary head pressure to eliminate this effect. Also, if the tank is filled up into the fill pipe the night before or at least four hours prior to the test, this will allow tank ends to stabilize.

- Vapor Pockets--When it is necessary to stabilize entrapped vapor pockets, a standpipe device can provide the necessary head pressure to reduce vapor pocket effect. Vapor pocket volume is reduced by pressurization of the standpipe with regulated pressure.

To eliminate the vapor pocket effect after a tank is filled up, if the standpipe device is not used, the vapor pockets are released by a "float tube" device designed for this purpose. The opening of the tube is connected to a float. Therefore, it is always situated at the top of the product in a tank (20).

- Evaporation--Since the test is usually conducted overnight, not in the heat of the day, evaporation effect is reduced especially when a test is conducted with the standpipe (20).

- Piping Leaks--If a leak is detected by EZY-CHEK tank testing, the EZY-CHEK line testor is used to detect the leak in the lines.

- Wind--If the weather is windy, the vent pipe is covered with a cap (20).

- Vibration--To minimize vibration effects, vehicles with considerable vibration effects are not allowed in the testing area or a test is conducted with standpipe (20).

- Noise--The effect of this variable on testing accuracy is insignificant (20).

- Equipment Accuracy--The recorder can easily detect a change of 0.005 inches in the liquid level. The temperature readout could be performed with 0.001 degrees Fahrenheit accuracy (5,18).

- Operator Error--This will be minimized by training and careful consideration of testing procedure (20).

- Type of Product--Testing could be performed with any type of product as long as air could be bubbled through the product and evaporation effect is insignificant (20).

- Power Variation--Recorder motor is spring wound and no electricity required. The temperature monitoring system is supplied with a 12-volt battery pack.

- Instrumentation Limitation--The detection method can be used for any type of liquid petroleum fuel storage tank (20).

- Atmospheric Pressure--The same barometric pressure is exerted on the liquid and the recorder's bellows; therefore, this variable does not affect test results (5,18).

- Tank Inclination--This effect is eliminated by recorder calibration by known volume at the beginning of a test (5,18).

Engineering Comments--In the EZY-CHEK testing method, the leak detection accuracy may be affected due to the following reasons:

- Difference between measured temperature change and the actual temperature change in the tank during a test period.
- Leak rate reduction due to the water table level.
- Unidentified vapor pockets. This is because the efficiency of the float tube has not been experimented thoroughly enough to assure that it could release all the existing vapor pockets in a tank.
- Product evaporation, when testing is performed on hot nights.
- Occurrence of wave due to wind and vibration. However, this effect is partially corrected by the chart results evaluation.
- Difference of theoretical tank volume and actual tank volume.
- Effect of atmospheric pressure change on vapor pocket volume (if any).

6- Fluid-Static (Standpipe) Testing (7,9,10,11)--

Description of Method (9,10)*--This detection method is known as "Hydrostatic Testing." However, hydrostatic terms refer to testing with water, but in underground tank testing the test is conducted with the product in the tank which is being tested. Therefore, in this text, "fluid-static" is used as a correct term for hydrostatic testing.

A standpipe is filled to pressurize a completely filled tank. The pumps in the siphon systems are removed from service and the manifold vent lines are disconnected. The pressure exerted by the fluid in the standpipe is generally enough to provide five psi pressure at the bottom of the tank. The volume change is calculated from the level change in the standpipe.

This method is not a manufactured system and can be used without special training by the gasoline service station operators. However, the method is not adequate for detecting slow leaks nor for determining tank system tightness and has an unspecified accuracy. Because the volume change due to a leak is accumulative, the accuracy of the test will increase if a long testing period is used and the system is near temperature and mechanical equilibrium.

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*Reported

Techniques to Compensate for Effects of Variables--This method does not compensate for the volume changes due to temperature changes, tank deformation, vapor pockets, and for evaporation for testing. However, when the testing time is increased, the effects of tank end deflection and other variables could be reduced in the final testing result.

Special precaution should be taken so that pumps in the siphon systems are taken out of service and that manifold vent lines are disconnected.

Engineering Comments--Due to the lack of compensation for major variables which affect the testing accuracy (unless a long testing period is used) this method is not adequate as a precision testing method to detect small leaks. An apparent loss of product is observed due to the expansion of the tank volume from tank end deflection and temperature changes. The magnitude of this apparent loss can be substantial. To detect a leak in this system, the leak must be greater than the volume variation resulting from tank end deflection and temperature changes. These effects could be minimized by using a long time period and permitting deflection equilibrium conditions.

The standpipe test method does not require specialized equipment or personnel. The testing is time consuming and the accuracy is unspecified. However, fluid-static testing is more sensitive than the pneumatic testing (9).

7- Heath Petro Tite Tank and Line Testing (Kent-Moore Testing) (4,5,7,9,10,11)--

Manufacturer's Description of Method (4)--This test is essentially a fluid-static (standpipe) test. The tank and standpipe (installed in the tank opening) are completely filled. A loss can be observed and measured to 0.01 gallons. A one-gallon graduate is used to measure the exact amount of gasoline added to or drained from the standpipe to maintain a constant level. The constant level results in a uniform tank pressure.

A circulating pump draws gasoline from at least six inches below the tank top through a suction tube; if necessary, the tube is lengthened by a hose extension. The gasoline is discharged under approximately 25 pounds per square inch pressure through a discharge hose into sections of tubing which have been coupled together to form an outlet jet at the bottom of the tank. This jet is adjusted to be above any water in the tank bottom and is adjusted to be below any drop tube. The jet is directed 45 degrees upward from the center line of the long tank axis. These suction and jet systems create a vortex-like swirling motion in the tank and attempt to produce a uniform temperature throughout the tank. Figure 18 illustrates the Petro-Tite testing method.

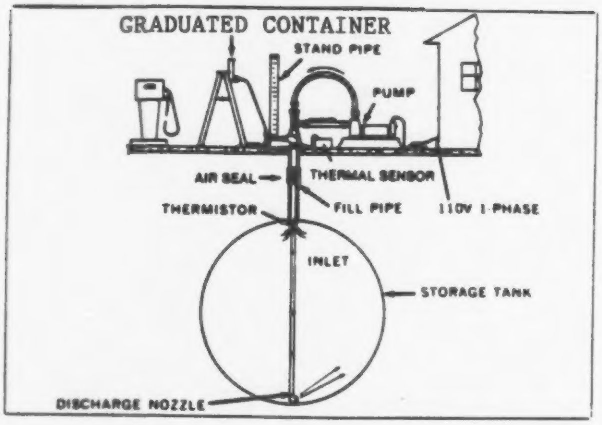
GRADUATED CONTAINER
STAND PIPE
PUMP
AIR SEAL
THERMAL SENSOR
THERMISTOR
FILL PIPE
110V 1-PHASE
INLET
STORAGE TANK
DISCHARGE NOZZLE

Figure 18. Petro Tite Installation (4)

Ref: Heath Consultants Inc., Petro Tite Tank Tester Bulletin

The uniform temperature obtained by circulation is electrically measured by a thermistor in the bottom of the suction tube. The thermistor is located approximately 6 inches below the top of the tank. Temperature changes are constantly measured. Volume changes are calculated from the temperature changes. The calculated volumes are subtracted from the volume change measured by the graduate. Measured volume changes are due to tank end deflection or leakage. Any difference between the calculated and measured volumes in the 15 to 30 minutes after tank end deflections cease, (approximately two hours), is considered to be leakage if it is equal to or more than 0.05 gallons per hour.

The minimum time to perform the test is 2.5 hours. The entire test can usually be completed in one working day (10).

Manufacturer's Techniques to Compensate for Effects of Variables (4)--In the Petro Tite testing method, the following effects of variables are compensated as described below:

- Temperature--This is done by using a thermal sensor and a temperature monitoring system. During the test, the product is constantly circulated to attain an average temperature. Circulation time is five to eight minutes per 1,000 gallons; five minutes for lighter liquids (gasoline) and eight minutes for heavier liquids (fuel oil). The thermal sensor is attached to a semiconductor thermistor probe in the tank and is capable of discerning 0.003 degrees Fahrenheit changes. By passing a small electric current through the thermistor, the average temperature is measured at the point of withdrawal six inches or more below the tank top. However, due to the overall accuracy and repeatability of the thermal system, the exact fraction of a degree Fahrenheit (i.e., 0.003 degrees Fahrenheit) varies slightly at different temperatures, which may cause some inaccuracy in the measurement of actual temperature changes. A chart gives the fraction for any temperature. Because the test takes several hours, accurate temperature monitoring can be accomplished.

- Water Table--The leak masking effect due to a water table is eliminated by inducing a constant pressure gradient on a leak. In addition, in areas with a water table and when there is no data available on the water level, the data should be obtained by drilling a monitoring well, prior to a test. The water level is used to determine the product level in the standpipe for testing.

- Tank Deformation--Apparent volume changes are compared with a chart to recognize the occurrence of tank end deflection. Volume changes are observed in equal time intervals and recorded on the Tank Test Data Chart. The manufacturer reports diminishing apparent losses in equal time intervals as end deflection occurs.

A technique has been developed to quickly eliminate these apparent losses due to tank end deflection. A high level, and therefore a greater pressure, is maintained at the beginning of the test in the standpipe. When recorded data indicate steadily decreasing losses, the product level, and therefore the pressure, is lowered, and tank end deflection usually disappears within two hours.

- Vapor Pockets--The presence of vapor pockets in the tank is recognized by direct observation of the bubbles in the standpipe. This is due to product circulation for temperature monitoring which carries some of the air to the fill pipe.
- Evaporation--Product loss by evaporation is minimized by using a cap to cover the graduate's top.
- Piping Leaks--For storage systems with submerged pumping, separate tests must be run on the tank and piping by the tank tester and line tester units. On suction delivery tank systems, the test checks the entire system simultaneously.
- Equipment Accuracy--The product volume change in the standpipe (tank) can be measured by using a one-gallon graduated cylinder. Volumes less than 0.01 gallons can be read on this cylinder (21). The temperature changes are constantly measured with 0.003 degrees Fahrenheit accuracy.
- Operator Error--This is minimized by using a skilled technician.
- Type of Product--As long as the product is of low enough viscosity to be free flowing, the method can be used to detect small leaks (21).
- Tank geometry, wind, vibration, noise, power variation, and instrumentation limitation do not appear to have significant effects on the applicability and accuracy of the detection method.

Engineering Comments--In the Petro-Tite method, the testing accuracy to measure leak rate may be affected due to the following reasons:

- Difference of measured temperature change with the actual temperature change in the tank.
- Water table level changing the leak rate.

- Leak rate measurement higher than the leak rate of normal tank operations. This is due to the use of fluid-static head greater than normal operating conditions.

- Unidentified vapor pockets.

- Difference between the theoretical tank volume and actual tank volume.

- Effects of atmospheric pressure change on vapor pockets volume (if any).

8- Helium Differential Pressure Testing (22)--

Manufacturer's Description of Method (22)--This test is an inert gas pressure test and is used to determine whether an underground tank is leaking and, if so, at what rate.

The tank is pressurized with helium after capping off all product and closing all vent lines connected to the tank. The tank pressure is compared to the pressure of a reference probe inserted in the tank. The tank pressure, differential pressure, and ambient temperature are measured at half-hour intervals for a minimum of 48 hours. The data provided by these measurements are sufficient to calculate whether any observed changes in tank pressure are due to leakage from the tank or are caused by the diurnal variation in ambient temperature. A leak rate less than 0.05 gallons per hour can be detected by this procedure. The equivalent volume of product lost during the test is computed from Bernoulli's equation for flow through an orifice.

Manufacturer's Techniques to Compensate for Effects of Variables (22)
--In this testing method, the following effects of variables are compensated as described below:

- Temperature--The pressure change due to the temperature change is compensated by using a reference tube inserted in the tank.

- Tank Deformation--The effect of tank end deflections is reduced by the 48-hour testing period (23).

- Type of Product--The type of product stored in the tank is compensated by including the product molecular weight in computation of gas density. Computed gas density is used in the leak rate computation.

- Vapor pockets, evaporation, tank geometry, wind, vibration, noise, power variation, instrumentation limitation, atmospheric pressure, and tank inclination are not applicable in this method of testing (23).

Engineering Comments--In this method, testing accuracy may be affected by the following reasons:

- Difference between the compensated (calculated) pressure change and the actual pressure change due to the temperature effect.
- The masking effect and leak rate reduction due to a water table level cannot be avoided.
- Differences between the actual tank geometry and the given geometry by tank manufacturer which is used for leak rate estimation.
- Piping leaks cannot be differentiated from tank leaks.
- The error in the measurement of differential pressure is reduced by installing the measurement device inside the tank. In this situation, the measurement will not be affected by ambient temperature change.
- The operator efficiency to tighten and seal the accessible ports and flanges. In addition, operator experience is necessary to use the appropriate printed differential pressure result to obtain the final leak rate.

9- Leak Lokator LD-2000 Test (Hunter-Formerly Sunmark Leak Detection) (5,7,10,11,24)--

Manufacturer's Description of Method (5,24)--This method operates on the Archimedes Principle of Buoyancy which states, "The apparent loss in weight of any object submerged in a liquid is equal to the weight of the displaced volume of the liquid."

The Leak Lokator consists of a hollow cylinder which is sealed at the bottom, an analytical balance (weighing scale), electronic transmitting circuitry, and a strip chart recorder. A sensor, suspended from the analytical balance, is placed in the tank liquid. The weight of the sensor is equal to its actual weight minus the buoyancy force from the liquid in the tank. Any change in liquid level will change the buoyancy force on the sensor and hence, the weight of the sensor. The weight change is monitored by the analytical balance which electronically transmits a "signal" to the recorder. The chart recorder graphically shows volume changes versus time. The angle and length of the line drawn by the recorder is directly correlated to the quantity and rate of leakage. Figure 19 illustrates the Leak Lokator testing method.

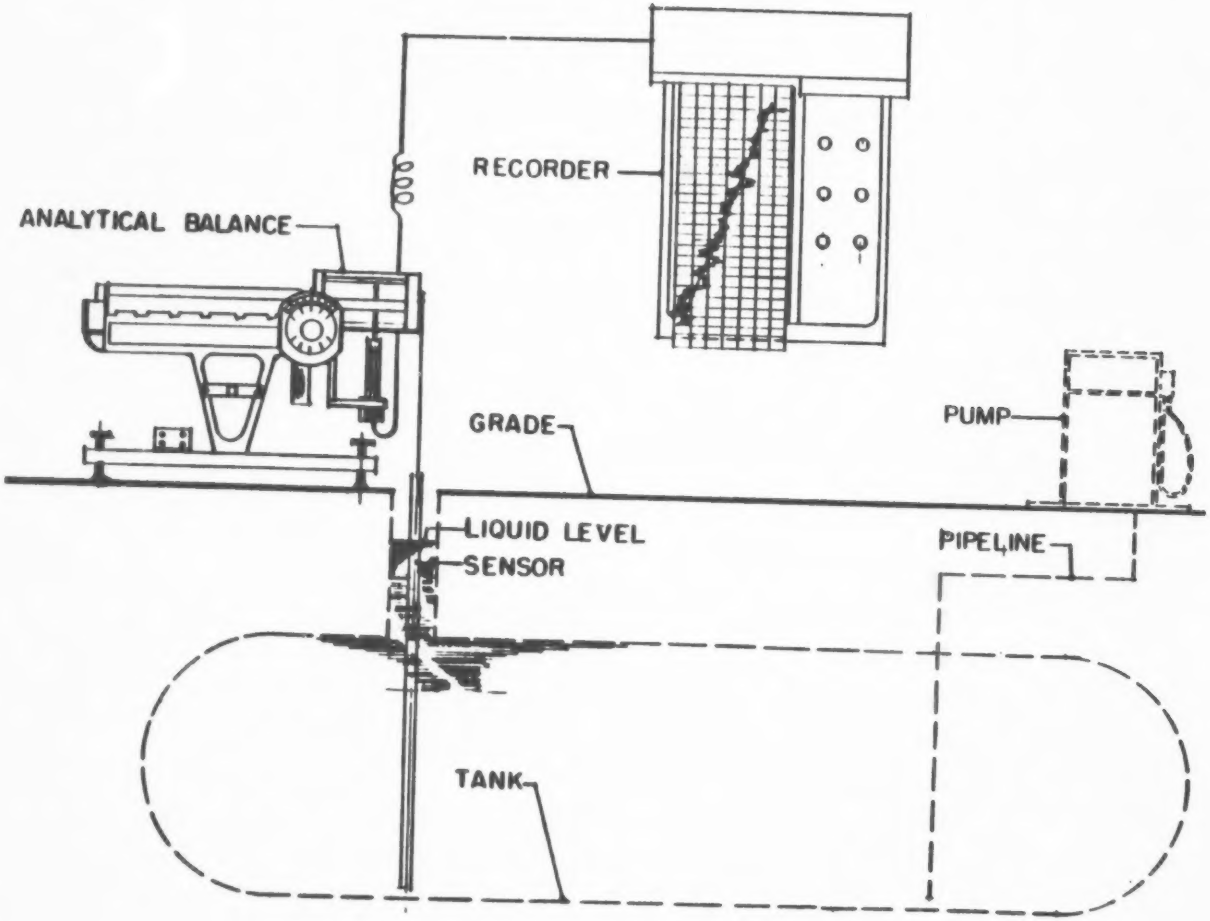
ANALYTICAL BALANCE
RECORDER
GRADE
PUMP
LIQUID LEVEL
SENSOR
PIPELINE
TANK

Figure 19. Leak Lokator Installation (24)

Ref: Hunter Environmental Services, Inc., Leak Lokator LD2000 Bulletin

The chart recorder notes the lapsed time in minutes versus volume change in cubic centimeters of the product displaced either into or out of the tank. A vertical line shows no change in volume, while lines with positive or negative slopes indicate decrease and increase, respectively, in the product volume. The system is calibrated at least six times during each test. This is performed by quickly adding or removing a calibration rod of precise known volume to the test system.

Typically, the time for equipment set up and temperature adjustment is 1.5 hours. A complete testing on one tank can usually be performed in 3 to 4 hours, and on four tanks in 8 to 10 hours. After the equipment is set up, the test to determine a volume change typically takes less than one hour. This time will increase to at least two hours for in-tank testing. The least sensitivity occurs when the product level is near the center line of the tank. However, even at this level, volume changes of 0.05 gallons per hour can be detected by adjusting test time and the electronic signal. The greatest sensitivity for detecting a small leak is achieved if the testing is conducted with the liquid in a riser above grade.

Manufacturer's Techniques to Compensate for Effects of Variables (5,24)--In the Leak Lokator testing method, the following effects of variables are compensated as described below:

- Temperature--This test compensates for temperature variation by lowering a thermistor to the center (midvolume) of the tank and measuring temperature change continuously during the test. The product temperature is stratified at various levels throughout the tank; however, it has been researched and proven to the satisfaction of this manufacturer that the midvolume location is a proper location to measure the average rate of temperature change for the entire volume as long as the strata are undisturbed, and the tank is buried and not subjected to ambient or unusual external effects. If a tank system is uncovered for any reason and subjected to ambient temperatures, or if the system is subjected to some other external source of temperature change, testing is conducted using three probes equally volume-spaced, and the average rate of temperature change is the volumetric average of the three probes. The signal from the probe(s) is electronically transmitted to a strip chart recorder and displayed on a digital meter with a resolution of 0.001 degrees Fahrenheit. The x-axis full-scale strip chart is typically set at one degree Fahrenheit (0.01 degrees Fahrenheit per division).

  In addition, to enhance the accuracy of the temperature compensation technique, a precise measurement of the product API specific gravity is made, on site, by taking a sample of the liquid being tested. The API gravity and observed temperature are then related to the coefficient of volumetric expansion using ASTM data.

- Water Table--If the water table level is known, the proper product level is used to overcome the forces of water outside the tank. When the water level is unknown, the test level is set assuming the water table is above the tank top. In addition, the level changes due to temperature changes during a test period virtually prevent the condition for a leak to be masked. This is due to the differences between the forces inside and outside a tank whenever the level changes.

- Tank Deformation--In this method of testing, because the pressure exerted by a fully charged system is only about one pound per square inch, the tank end deflection is minimized. In addition, because the most significant effect of deflection occurs almost immediately after a system is topped off, end deflection is typically not a problem. If for some reason fill pipe product levels must be raised higher than normal for testing, charts are provided by the manufacturer to compensate for related volume changes. If tank end deflection is significant, the test slope will be erratic and inconsistent, thereby indicating the need to compensate by raising and lowering the level.

- Vapor Pockets--Due to the short duration of the test, vapor pockets compensation is rarely required because vapor pockets only affect test results when ambient barometric pressure or temperature changes significantly during a test period. If the pocket size is four gallons or less, and if the barometric pressure change is less than 0.02 inches Hg per hour, no corrections are needed. Tables are provided to compensate for changes greater than 0.02 inches Hg per hour. In addition, if vapor pockets are present and affected by temperature or pressure, the test slope will be erratic and inconsistent, thereby indicating the need to compensate and/or eliminate the pockets until conclusive results can be obtained.

- Product Evaporation--In this method, a hollow sensor is used to compensate for product evaporation. This sensor is sealed at the bottom, filled with the product, and suspended for testing to a point a few inches higher than the product level in the tank. The inside diameter at the top of the sensor is slightly larger than where the sensor enters the product so that the surface area inside the tube is the same as the surface area occupied by the tube in the product. For this reason, evaporation takes place from the surface area of the sensor at the same rate as from the surface area of the product measured. As evaporation occurs from the hollow tube, the sensor becomes lighter. However, the buoyancy force exerted on the sensor by the product in the tank decreases at the same rate due to evaporation, thus entirely compensating for evaporation effects.

- Piping Leaks--If a leak is found during the full system test, with the product level raised so that all buried piping is being tested, the level is then lowered to tank top (within one to six inches) and another test is conducted to check leaks in only the tank.

- Vibration--Vibration factors, such as traffic may cause the leak rate slope to fluctuate; however, the rate of change is easily determined by drawing a slope through the fluctuations. The most significant effects of vibration occur during in-tank testing.

- Equipment Accuracy--The reading accuracy for volume change is calculated by chart calibration with addition or removal of product to optimize the chart deflection per calibration. The electronic voltage signal is also optimized to minimize the volume calibration per division. The temperature readout is provided at 0.001 degrees Fahrenheit accuracy on a digital display. Both temperature and volume change are continuously recorded.

- Operator Error--The operator error is minimized by using a crew of trained operators (25). All testing services are provided by Hunter employees.

- Type of Product--The method can be performed effectively on any products or mixture of products where the sensor can be freely suspended.

- Instrumentation Limitation--The test can be conducted in any size underground tank system with two-inch or larger opening. However, for in-tank testing, a minimum opening of four inches is required.

- Atmospheric Pressure--It has been determined that a barometric pressure increase during the test period would have to exceed 0.07 inches Hg in one hour to effect an apparent leak of 0.01 gallons per hour. Because a pressure increase is generally slower than a pressure decrease and therefore would not occur during the short test period, it is normally not necessary to compensate; however, charts are provided in the operator's manual if this unusual circumstance occurs.

- Tank Inclination--The effect of tank inclination is eliminated by testing calibrations (25).

Engineering Comments--In the Leak Lokator testing, the accuracy may be affected due to the following reasons:

- Difference between measured apparent temperature change and actual temperature change.

- Leak rate change due to the water table effect; therefore, the water table masking effect cannot be avoided.

- Tank end deflection, if it is unidentified.

- Vapor pockets. When the volume of the vapor pocket is unidentified, there is no way to measure its volume changes due to temperature and barometric pressure changes during a test period.

- Occurrence of wave due to wind and vibration. However, this effect is partially corrected by the chart results evaluation.

- Difference between theoretical tank volume and actual tank volume.

- Power variations due to the use of 110V AC power source.

- In some cases, the fill pipe is at such an angle from vertical that the sensor could not be installed in the tank without touching the wall. Therefore, tank testing is not possible by this method.

10- Mooney Tank Test Detector (5,7,10,26)--

Manufacturer's Description of Method (5,26)--In this method, an underground storage tank is filled with product into the fill pipe. The test starts 12 to 14 hours after product delivery. The product level and the temperature of the liquid within the tank are monitored over a one-hour period with 20-minute testing intervals. A leak as small as 0.02 gallons per hour can be detected (27). If the elevation of the liquid in the fill pipe changes from the level caused by expansion or contraction due to temperature changes, and by evaporation loss, this indicates a leak in the tank.

In the past, level changes were monitored by either a mechanical float device or an electronic capacitance probe (27). The electronic type could provide a digital readout of 0.01 inches of level change. At the present time, a dip stick graduated at 0.05-inch divisions is used to measure the level. One side of the dip stick is covered with gasoline or water indicator paste and inserted into a tank. To increase the level measurement accuracy, the dip stick is connected to a leveling device which sits on the opening of the fill pipe. The instrument box is capable of testing three tanks at the same time.

Manufacturer's Techniques to Compensate for Effects of Variables (5,26)--In the Mooney Leak Detection testing method, the following effects of variables are compensated as described below:

- Temperature--The average temperature of the tank is measured by monitoring the temperature at the center of each of five layers with equal volumes. The device includes an electronic temperature differential measuring system consisting of five electronic sensors and digital readout. The anticipated accuracy for temperature measurement is in a range of 0.001 to 0.006 degrees Fahrenheit.

- Tank Deformation--In this method, the significance of the tank end deflection effect is minimized by filling the tank up into the fill pipe 12 to 14 hours before the test period.

- Evaporation--This system uses an evaporation cup as a measuring device. The cup is filled and installed in the fill pipe. The height of product which evaporates from the cup during the test period is measured. This height is equal to the height of the liquid evaporated from the fill pipe and will be considered as the final resultant evaporation.

- Piping Leaks--If a leak is detected, the level of the product is lowered in the fill pipe to below the top of the tank, and a complete set of testing is performed (27). This test will identify if a leak is in the piping.

- Equipment Accuracy--The level measurement device "dip stick" is divided to 0.05-inch divisions. The temperature readout could be provided with 0.001 degrees Fahrenheit accuracy on a digital display.

- Type of Product--The type of the product will not affect the testing accuracy as long as the level change of liquid can be determined on the product indicator paste (27).

- Tank Inclination--This effect is compensated by calibration for level reading at the beginning of each testing period.

- Instrumentation limitation and power variations have insignificant effects on the detection method (27).

Engineering Comments--In the Mooney Tank testing method, the accuracy of the results may be affected due to the following reasons:

- Difference between the measured temperature change and the actual temperature change during the test period.

- Leak rate changes or masking due to water table effect.

- Unidentified vapor pocket(s).

- Difference between theoretical tank volume and actual tank volume.

- Error in level reading due to vibration by wind and traffic.

- Operator accuracy in reading the product level changes from the dip stick.

- Rapid change in barometric pressure.

11- PACE Leak Tester (28)--

Manufacturer's Description of Method (28)--In testing with the PACE Leak Tester a tank is nominally filled, at a product level several inches below the top of the fill pipe, about 12 hours before testing is started to allow the temperature to stabilize. The tank's vent and feed pipes are sealed except for one which is fitted with a "dip tube." Measurements of the liquid level in the dip tube are taken during the course of the testing.

The system consists of a small-diameter tube (dip tube) as the test tube, a wooden ruler to measure the product level in the dip tube, three thermocouples to read product temperature, and a barometer to read atmospheric pressure. The dip tube is welded into a cap that is then threaded onto the testing tank's fill pipe in such a way that the dip tube extends above the fill pipe. It is possible to gain access to the stored product through this open-ended pipe. During the tank testing, this pipe is the only access point to the product. The presence of the void above the product level in the tank converts the dip tube into one arm of a manometer that measures the difference in pressure between the gas in the void and the atmosphere outside the tank. The product levels within the tube and the tank will both change in response to a leak or to a temperature change. The change of the void pressure due to a leak is magnified in the dip tube. The recommended procedure is to install thermocouples at three specific locations at the top, middle, and bottom of the tank.

Four consecutive measurements of product level in the dip tube, and temperature measurements are made at approximately half-hour intervals spanning a 1.5-hour period. In addition, the atmospheric pressure is measured at the beginning and end of the testing. The results are analyzed and leak rates are derived using a simplified calculation.

The computed leak rates can also be assessed statistically. The statistical analysis performed can also be calculated on the three estimated leak rates to produce an overall average and corresponding standard error. If this overall average is not greater than the largest of the four leak volume error values, then the experiment indicates that a leak (if present) is less than the intrinsic error of the experiment. If the overall average is greater than the largest error, but is not more than eight ounces per hour greater than the largest error, then the experiment has not detected a leak greater than the NFPA leak detection limit of eight ounces per hour (0.05 gallons per hour).

The PACE Tank Testing is in principle a simple, accurate, and practical test, which has been theoretically and experimentally tested in a program conducted for the Petroleum Association for Conservation of the Canadian Environment. This method is not commercially available.

Manufacturer's Techniques to Compensate for Effects of Variables (28)--In testing with the PACE Tank Tester, the following effects of variables are compensated as described below:

- Temperature--When a tank is filled with product, the test will be conducted after a 12-hour temperature stabilization period. Based on statistical evaluation, it is found that three thermocouples are satisfactory to measure the product temperature at the top, middle, and bottom of the testing tank. The accuracy of each thermocouple is 0.01 degrees Fahrenheit. After the initial temperature measurements, the measurements will be repeated at three equal intervals of a half-hour. These measurements are used to compute the mean value of the expansion effect and its standard error. In some experiments (during the summer) this statistical error is the factor limiting the accuracy of the measured leak rate.

  The measurements for three test repetitions also allow for a statistical estimate of the overall error in measuring the leak rate.

  The thermal expansion of the liquid gasoline is the largest perturbation in this method and is always significant. It is imperative that thermal expansion be compensated.

- Tank Deformation--The fill/empty cycles during the normal operation of a tank should compact the backfill material adjacent to the tank ends. This results in a void between the ends and the limit of the deflections. If the movement of the ends is unrestrained, the deflection will occur immediately after filling. In addition, a 12-hour temperature stabilization period also ensures that the end deflection is not a significant factor.

- Product Evaporation--It is calculated that the effect of product evaporation due to the increase of the void volume by a small leak is negligible.

  The evaporation effect due to change of product vapor pressure by temperature change is compensated by obtaining the vapor pressure from the Reid Chart and is based on the top thermocouple temperature reading.

- Tank Geometry--The effect of the tank geometry on the void volume above the product level is minimized by initial calibration. The initial depth of the product from the top of the dip tube is measured with a ruler. Finally, a measured volume of product, about 0.05 gallons, is removed from the tank with a syringe inserted into the dip tube. This creates an artificial leak and the new depth of the product in the dip tube is measured. Since these all take place within about one minute, the temperature and atmospheric pressure are considered constant and hence the artificial leak without expansion effect is measured.

- Vibration--In this method, due to the magnification of the product level change in the dip tube, the vibrations due to such things as vehicle traffic do not have a significant impact on the results.

- Equipment Accuracy--The accuracy of this method is especially affected due to temperature variation. In a 5,000-imperial-gallon tank, the intrinsic error in the temperature measurement (0.005 degrees Fahrenheit) corresponds to an expansion effect of 2.5 ounces (0.015 gallons). The accuracy is increased during the winter period. It is estimated that in this method accuracies of 0.125 inches, 0.01 degrees Fahrenheit, and 0.1 inches of mercury for ruler, thermocouples, and barometer, respectively, are sufficient.

- Operator Error--This method is invented to provide a method with little or no requirement for operator training.

- Instrumentation Limitation--Since the temperature is only measureable to the nearest 0.01 degrees Fahrenheit, this limitation may be more important than the statistical error value.

- Atmospheric Pressure--The main effect of a change in atmospheric pressure is on the level in the dip tube. Other effects such as a change in volume of the tank and the liquid within it are bound to be negligible for the small changes of pressure experienced as the weather changes. In addition, the steel tank and its product contents are effectively incompressible. The atmospheric pressure could be measured with a barometer at an accuracy of 0.1 inches of mercury. However, under normal conditions the change in atmospheric pressure over the short period of the test (1.5 hours) will not significantly affect the results and hence this measurement can normally be eliminated.

Engineering Comments--If the void space above the product level behaves as an ideal gas, the testing results with the PACE Tank Tester will be theoretically acceptable. However, any deviation of the void space from ideal gas behavior will affect the accuracy of the testing. This method is a developing method with limited experimental trials on steel underground storage tanks and none on fiberglass tanks. Therefore, there is not sufficient data and evidence available to conclude that the void space behaves as an ideal gas.

In this testing method, the detection accuracy may be affected due to the following reasons:

- Lack of proper technique to measure the representative temperature of the product and the void space. These will affect compensation for evaporation due to inadequate estimations of product vapor pressure.
- Water table effect on the leak rate cannot be prevented. In some cases, the leak may be completely masked due to the water table effect.
- Vapor pocket effect may be insignificant, due to short period of testing.
- Product evaporation due to the dip tube with an end open to the atmosphere.
- Piping leaks into the tank.
- Wind effect on product evaporation rate due to the presence of the dip tube with an open end to the atmosphere.
- Noise will not affect the detection accuracy.
- Type of product will affect the vapor pressure and the rate of the evaporation.
- The power variation effect can be minimized by using a new battery for each tank testing, since the digital thermocouples in this method are the only electrical components.
- Since the product level is measured in a dip tube with 1.5-inch-diameter, the tank inclination effect on the detection accuracy will be insignificant.
- The precision of the method is overstated (the entire statistical analysis should be carefully reviewed).

12- PALD-2 Leak Detector (10,29)--

Manufacturer's Description of Method (29)--In this method, a completely filled underground storage tank is pressurized with nitrogen to allow the level to rise within a sensing column to a viewing window above ground level. The tank is pressurized to at least three different pressures during the course of testing. All ports and vents to the atmosphere must be closed and/or sealed.

The system consists of a nitrogen cylinder, a pressure measuring device, a series of electro-optical level sensors, a microprocessor, and a printer. The level changes are detected through electro-optical sensors. The microprocessor determines the validity of the readings and sends the calculated leak rate to the printer. The leak rate is calculated based on the size of the leak and on the pressure difference across the leak. The testing depends on the requirement to rapidly settle the tank after each pressure change. This is accomplished by raising the gas pressure above the test pressure for a short duration. Care must be taken not to go beyond the equilibrium point. The sensitivity of the system is high (less than 0.05 gallons per hour) and monitoring time short (less than 15 minutes).

Manufacturer's Techniques to Compensate for Effects of Variables (29) --In the PALD-2 testing method, the following effects of variables are compensated as described below:

- Temperature--The temperature effect is minimized by the short duration of the testing in an equalized condition.

- Tank Deformation--The effect due to this variable is minimized by the short duration of the testing in an equalized condition.

- Vapor Pockets--Presence of entrapped air has a serious negative effect on the test quality and it should be removed prior to testing, at all cost.

- Instrumentation Limitation--Care must be taken not to go beyond the equilibrium point. If this occurs, the tank will contract during the measurement and a negative volume change will be indicated. In this case, the test may be abandoned and repeated at a later time or the microprocessor may be reprogrammed to repeat the test at a slightly higher pressure.

- Other sources of error are: ground water table, ground motion introduced by external sources, oscillations within the tank system, and atmospheric pressure changes. However, the method to reduce most of these errors is to allow ample time for the tank to settle.

Engineering Comments--In this testing method, the detection accuracy may be affected due to the following reasons:

- Temperature effect on volume change may be significant, as compared to the measured volume change during a short testing period.

- Leak rate change by the water table effect and leak rate enhancement due to the application of pressure greater than the normal operating condition.

- Piping leaks.

- Equipment accuracy.

- Power variations.

- Product evaporation, tank geometry, wind, operator accuracy, type of product (with similar vapor pressure), and tank inclination do not appear to affect the quality of the test.

In addition, in this testing method, the following disadvantages are noticeable:

- Due to the use of pressure greater than the normal operating pressure, the leak rate increases during the course of testing.

- There is a risk that tanks weakened by corrosion will be ruptured by pressurization.

13- Pneumatic Testing (7,9,10,11)--

Description of Method (9,10)*--In this method, which is not a manufactured system, the storage tank and the piping systems are pressurized with air or another gas. The pressure change depends on the change of gas volume in the tank and piping. However, this method does not compensate for any variable changes during the testing period. The method is not sensitive to small leaks and is not likely to detect leaks below the liquid level in the tank. In addition, the piping and tank leaks could not be differentiated from each other.

Techniques to Compensate for Effects of Variables (9,10)*--The tank end deflection effect could be reduced during the testing period. However, this method will not compensate for other variables which may affect the testing results. Greater accuracy can be achieved, when the tank is full or nearly full.

Engineering Comments--In the pneumatic testing method, the following problems could be noticed:

- Air pressure and vapor pressure of the stored liquid in the tank vary greatly with temperature. The temperature effect can be measured, but this method does not compensate for pressure changes resulting from temperature variation and tank end deflections.

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*Reported

- Water table changes in or masking of the leak rate cannot be avoided.

- The method does not compensate for pressure changes due to tank end deflections.

- If the pressure exceeds the tank's normal operating pressure, there is a risk of tank rupture, especially if the tank is badly corroded. The more product in the tank, the more the risk of overpressurization should be considered.

- A faulty or inaccurate gage may allow overpressurization and lead to a tank explosion or rupture. This should not happen if equipment is properly calibrated.

- Potential increase in leak rate during the test period (and, possibly, after).

- Testing with air in tanks containing flammable and/or combustible liquids is extremely hazardous (3).

- Due to the exertion of additional pressure on the tested tank, product may be forced out of the tank at leaks during the test period.

- The method is time consuming and the accuracy is unspecified.

14- Tank Auditor (30)--

Manufacturer's Description of Method (30)--This is an electromechanical system for detecting leaks in underground piping and tank systems. The method operates on the Archimedes Principle of Buoyancy.

The major component of this system consists of a product height deviation transducer, a temperature probe height deviation transducer, a temperature probe, and a recorder. A force deflection transducer supports a negatively buoyant member within the liquid-filled fill pipe. Buoyancy forces are changed due to product level change and create a linear deflection of the force transducer that is sensed by a noncontact electronic probe with a voltage output proportionate to the deflection of the force transducer. The temperature probe, consisting of a thin-walled hollow cylinder closed at the bottom and opened at the top, is placed into the fill pipe. The length of this probe is equal to or greater than the tank diameter. The probe is filled with product. A force transducer, similar to the product height deviation transducer, is used to sense height deviations within the probe. A recorder receives the output voltage from the transducers and the results are printed on a strip chart. At the end of a 15-minute test, the recording is stopped. The total volume change due to a leak is calculated. At the beginning and end of each test, both transducers are calibrated by addition and/or removal of known volumes of the product from the temperature probe and the tank.

If the tank is filled prior to a test, the test is conducted at least three to four hours after tank fillup (31). The average time required to test a single tank, including setup and dismantling, is one hour. Typically, an additional hour of testing is required due to unusual situations such as piping leaks, tank leaks, presence of an air pocket, syphon systems, and common vents. The detection method has an accuracy of 0.05 milliliters (0.00001 gallons) gross volume change in a four-inch fill pipe and 129 milliliters (0.03 gallons) gross volume change in a half-full, 10.5-foot-diameter tank. Therefore, the tank could be tested even when it is partially full.

Manufacturer's Techniques to Compensate for the Effects of Variables (31)--In the tank auditor detection method, the following variables are compensated as described below:

- Temperature--A thin hollow copper tube, filled with product, is used for temperature compensation. This probe can be used when the fill pipe diameter is larger than three inches.

- Water Table--The complete masking effect of ground water is eliminated by performing tests at the bottom and the top of the fill pipe. Because the static head changes, a leak cannot be completely masked.

- Tank Deformation--If the system is filled prior to a test, major tank deflection occurs immediately after tank fillup. Further effects will be reduced or eliminated by three to four hours waiting period before a test.

- Vapor Pockets--If the presence of vapor pocket is recognized, the level of the product will be lowered below the tank top and the test performed. However, piping leaks will not be determined and the time for testing will be increased.

- Product Evaporation--Because the product level changes due to product evaporation in the fill pipe (or fill tube) and in the temperature probe are equal, the effect is compensated for simultaneously with compensation for temperature change.

- Piping Leaks--Piping leaks are determined by performing tests at the bottom and the top of the fill pipe. If a leak is identified, the elevation of the leak will be determined by adjusting the product level.

- Tank Geometry--When the tank is partially filled, this effect is eliminated by the testing calibration.

- Wind--Wind effect is minimized or eliminated by electronic dampening and performing the testing under a tent.

- Vibration--This method is relatively insensitive to vibration due to mounting on the tank fill pipe.

- Equipment Accuracy--A level change due to 0.05 milliliters (0.00001 gallons) volume change in a four-inch fill pipe and 129 milliliters (0.03 gallons) volume change in a half-full 10.5-foot-diameter tank can be measured by the product deviation transducer. The sensitivity of the temperature measurement probe is to 0.015 degrees Fahrenheit.

- Operator Error--This is minimized by defined testing procedures and operation by trained personnel.

- Type of Product--The detection method could be used for any product as long as the probes can sink.

- Instrumentation Limitation--The fill pipe must be vertical to the extent that a plumb bob can be hung four inches into the liquid from the top of the fill pipe at any point on the circumference of the pipe without touching the side of the fill pipe at the lower end. The probe must hang vertically into the product from the fill line, vent, or manhole. Some fill pipes are at such angles from vertical that testing is not possible. A piping and tank system test is always possible. In addition, the temperature probe can be used when the fill pipe diameter is larger than three inches.

- Tank Inclination--As long as tank inclination does not prevent the equipment utilization, its effect is eliminated by calibration of the chart at the beginning and end of a test.

- Noise, power variations, and atmospheric pressure do not generally affect the detection method accuracy.

Engineering Comments--In the Tank Auditor detecting method, testing accuracy may be affected by:

- Difference between the product level changes in the tank and the reference tube due to temperature change.

- Leak rate changes due to the water table effect cannot be avoided.

- Volume changes due to an unidentified tank end deflection three to four hours after tank fillup, during a testing period.

- Unidentified vapor pockets in a completely filled tank.

- Power variations.

- Effect of atmospheric pressure change on vapor pocket volume (if any in a completely filled tank).

15- Two-Tube Laser Interferometer System (9,10,29,32,33)--

Manufacturer's Description of Method (29)--The Two-Tube Laser Interferometer System simultaneously measures the difference in the height of the product in an open tube and a closed tube initially filled to the same level. The height changes in the open tube caused by the principal noise sources that could hide a small leak in a partially filled gasoline storage tank (e.g., thermally induced volume changes and evaporation/condensation) are removed (i.e., compensated for) by subtracting the height changes in the closed tube.

The major components of the system consist of the laser interferometer measurement system, two equal length two-inch-diameter tubes extending to the bottom of the tank, an aluminum float (for each tube) containing a cube-corner reflector, and a data acquisition system. The laser system consists of a laser head, laser display unit, a beam splitter, and two interferometers mounted on a solid cast aluminum stand. The laser head generates a safe, low-power (200 μW) beam which is divided into two beams for the height measurements in each tube. Because the interferometer is not attached to the laser head, motion of the laser head does not affect the measurement. The data acquisition system receives the laser interferometer height measurements made at a 200 Hz sample rate, averages the data over a 42-second period, and generates a time series at one-minute intervals for the leak detection analysis. Figure 20 schematically illustrates the system.

The laser interferometer measurement system itself measures height changes to one micro-inch (0.000001 inch). The accuracy of the Two-Tube Laser Interferometer System to measure a known product level change is 60 micro-inches; this was determined by making repeated measurements of the height changes in an 8,000-gallon storage tank produced by inserting and removing several different solid aluminum bars of known volumes.

The accuracy of the system for detecting small leaks in an underground storage tank was estimated from the analysis of data collected during many field experiments (29). The analysis showed that a leak rate of 0.041 gallons per hour could be detected with a probability of detection of 95 percent and a probability of false alarm of 0.1 percent assuming the tank was 75 percent full. The time period of the tank test to achieve this performance is two hours.

The system was used in an experimental program conducted for the American Petroleum Institute (29,32,33) and is not available on the commercial market.

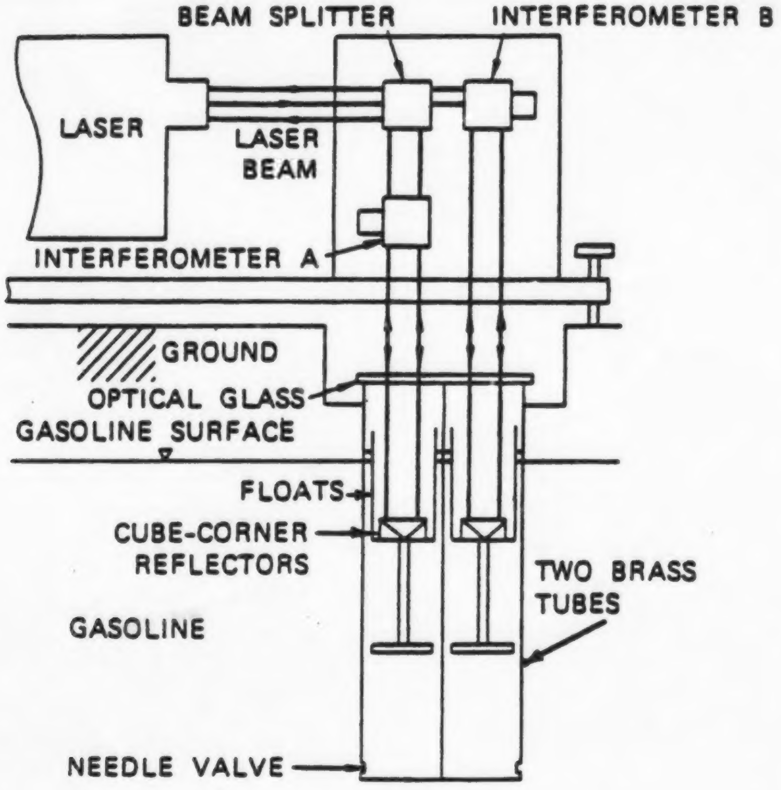

BEAM SPLITTER
INTERFEROMETER B
LASER
LASER BEAM
INTERFEROMETER A
GROUND
OPTICAL GLASS
GASOLINE SURFACE
FLOATS
CUBE-CORNER REFLECTORS
TWO BRASS TUBES
GASOLINE
NEEDLE VALVE

Figure 20. Two-Tube Laser Interferometer (32)

Ref: Underground Tank Testing Symposium, Petroleum Association for Conservation of Canadian Environment (PACE), May 25, 26, 1982

Manufacturer's Techniques to Compensate for Effects of Variables (34)

--In the Two-Tube Laser Interferometer System testing method, the following effects of variables are compensated as described below:

- Temperature--Because the method uses two tubes (one closed and one open end tube), the temperature effect is compensated automatically (29,32,33).
- Water Table--If the first testing result indicates a nonleaking tank, the water table masking effect could be checked by conducting the test at levels lower or higher than the level in the first test (or by measuring the depth of the water table).
- Tank Deformation--The effect of this variable is eliminated because the test is performed at normal operating conditions.
- Vapor Pockets--Vapor pockets are not a problem because the testing procedure does not require the tank to be full.
- Product Evaporation--Since the level changes due to product evaporation in the open and closed (reference) tubes are equal, this effect is compensated for simultaneously with the compensation for temperature changes.
- Tank Geometry--This does not affect the result because the system is calibrated for level changes due to a known volume change, before the test.
- Vibration--Waves in the tank due to the vibration effect is not a problem because the raw laser height data is averaged over a time period which is long compared to the wave period. In addition, vibration of the ground is not a problem because these effects are small and are removed by the two-tube measurement. Also, vibration of the laser head is not a problem because the laser is separated from the interferometer.
- Equipment Accuracy--The resolution of the Two-Tube Laser Interferometer measurement systems used in field tests is 1 micro inch. The data acquisition system is used to store the data after rounding off the data to the nearest 10 micro inches. The system's reported accuracy is within ±60 micro inches. The height change associated with a 0.05-gallons-per-hour leak in a 3/4-full, 8,000-gallon, 8-foot-diameter tank is 530 micro inches.
- Type of Product--The type of product will not affect the testing accuracy.

- Tank Inclination--The effect due to this variable could be minimized by calibration of the system on site.

Other potential sources of error in the height measurement were investigated: thermal expansion or contraction of the laser equipment and mounting stand, thermally induced changes in the tubes' diameter, vertical alignment of the beam, changes in the refractive index of the light between the interferometer and the corner-cube reflectors, settlement of the mounting stand, and expansion or contraction of the ground relative to the gasoline storage tank. Each of these errors were theoretically estimated, quantified experimentally, and rejected because they were small.

Engineering Comments--In the Two-Tube Laser Interferometer testing method, testing accuracy may be affected by the following:

- Differences between product level changes in the tank and the reference tube due to temperature change.

- Leak rate change due to the water table effect cannot be avoided.

- Vibration, strong enough to produce long waves which masks height changes due to a leak.

- Operator skill to set up the test equipment.

- Power variations.

Nonvolumetric (Qualitative) Leak Testing Methods

1- Acoustical Monitoring System (AMS) (35)--

Manufacturer's Description of Method (35)--The acoustical monitoring system can be used for detection of leaks in an underground storage tank. This system includes the development of advanced instrumentation for signal detection and processing, the development of signal interpretation methodology, and the use of the triangulation technique for locating leaks. Acoustic signals, generated when pressurized liquids escape through a metal boundary, are detected by piezoelectric transducers attached to the surface of the pressure boundary. Nitrogen is used to pressurize the tank. In this measurement, accelerometers (resonant at 27 kHz) are used in conjunction with a wave guide mounted acoustic emission sensor (resonant at 250 kHz). With this combination of sensors, the range of frequencies of flow-induced vibrations and elastic waves due to a leak can be monitored.

In an actual field test, the AMS system was able to detect leaks, as indicated by the Petro-Tite system, of 0.01 gallons per hour. This method is not commercially available and is subject to more experimental studies.

Manufacturer's Techniques to Compensate for Effects of Variables--The major variables considered for volumetric testing systems are not applicable to this method. In addition, other variables are not identified by the manufacturer which can affect the testing accuracy.

Engineering Comments--For the AMS detection method, the following are noted:

- Does not provide leak rate.
- If the nitrogen pressure exceeds the tank's normal operating pressure, there is a risk of tank rupture, especially if the tank is badly corroded.
- Potential increase in leak rate during the test period (and, possibly, after).
- The testing method on tanks containing flammable and/or combustible liquids is extremely hazardous (3).

One of the advantages of the AMS method is the capability of determining the leak's location in the tank.

2- Leybold-Heraeus Helium Detector, Ultratest M2 (5,7,10,36)--

Manufacturer's Description of Method (5,36)--In this method, helium is used as a tracer gas for leak detection. With the vent line plugged, the tank is pressurized with helium gas to four pounds per square inch. The gas is fed at the bottom of the tank so that it mixes thoroughly with the product in the tank.

To detect helium, five small holes must be drilled and located over the corners and center of the tank. The sniffer probe of the detection system samples the gas in each hole and the helium is detected using mass spectrometric techniques.

Manufacturer's Techniques to Compensate for Effects of Variables (5,36)--The testing method can detect leaks only by detection of helium through the monitoring holes outside the tank and is thus not affected by the variables discussed for other methods.

Engineering Comments--The method cannot measure leak rate. In addition, due to the presence of product in the tank, ground water, and ground characteristics (especially for tanks with clay backfill), testing may require a long period of time before a small leak is detected. One other reason which reduces the detection speed is that helium does not flow freely through liquid (37). However, the method does not require the tank or pipes to be removed from service during the testing.

The five holes may provide an approximation of the location of the leak (if further tracing of the leak is required).

3- Smith & Denison Helium Test (7,37)--

Manufacturer's Description of Method (37)--This method of leak detection is based on differential pressure loss in the tank being tested relative to a reference steel chamber equipped with a differential pressure manometer or gage. Excess pressure (over ambient pressure) is induced by inserting helium gas into an empty tank and the reference chamber. The pressure loss with time is monitored to indicate leaks in the system. In addition to pressure loss, gas escaping from a leaky system is detected, at ground level, by sampling the gas in the soil pore space and measuring the concentrations of helium by a mass spectrometer. This requires drilling small holes into the soil around the tank or pipe. Testing is performed in two steps--one step with the product in the tank (no level change prior to the test) to verify the tank and piping are sealed above the product level (this test can usually be performed in less than four hours while the tank is in service) and one step when the tank is completely empty. The pressure change in the test tank resulting from temperature change during the test period is compensated for by the pressure change of the reference chamber. The reference chamber can be in thermal equilibrium with the helium gas in the tank one hour after the testing is started (38). Leaks from tanks usually are detected very quickly. A search for helium gas around the tank is conducted soon after differential pressure equilibration. In some cases where the tank is protected by a clay backfill, it may be necessary to continue the test for 24 hours before helium gas is detected at the soil surface. If the concentration of the helium in the soil gas is more than five ppm (helium concentration in the air), the system is leaking. In this method, the size of the leak opening and therefore the maximum possible fuel leak rate could be calculated. The manufacturer's literature did not quantify a leak rate (38) because it depends on the location of the leak in the testing tank, but did describe the relationship between the size of an opening and the overall measured helium loss during the testing.

Manufacturer's Techniques to Compensate for Effects of Variables (37)
--In this testing method, the following effects of variables are compensated as described below:

- Temperature--A reference steel chamber is used to compensate for pressure change due to temperature change, which is done by measuring the differential pressure of the tank and the reference chamber during a test period. The reference chamber can be in thermal equilibrium with the helium gas in the tank one hour after the testing is started (38).

- Water Table--The presence of a high water table surrounding the tank prevents the exit of helium from the tank. However, this can be overcome by increasing the helium pressure until it exceeds the ambient pressure and can then bubble up through the liquid to the surface.

- Tank Deformation--This effect will be eliminated by evaluation of the printed record on pressure differential of the tank which is conducted for at least four hours (38).

- Piping Leaks--These leaks could be identified during the first step of testing, when the test is conducted with product in the tank, and/or during the second test by the detection of high concentrations of helium around piping.

- Equipment Accuracy--Differential pressure is measured by a manometer or an electronic differential pressure gage, installed inside the tank, with 0.01 or 0.1 inches of water reading accuracy (37). The sensitivity of the helium leak detection method is sufficient to indicate leak size which would result in a gasoline leaks as small as 0.005 gallons per hour. However, because the leak rate is dependent on the location of the leak, this method cannot provide the actual leak rate (38). Modern helium mass spectrometers can detect helium concentrations as low as 0.1 parts per million.

- Operator Error--Prior to conducting the test, all the ports are sealed by the testing operator. However, a potential source of error is helium leakage through these ports even after they are tightened by the operator. However, this method is capable of identifying these types of leaks.

- Atmospheric Pressure--The effect of barometric pressure change is eliminated by using a device to measure differential pressure.

- Vapor pockets, product evaporation, tank geometry, wind, vibration, noise, type of product, power variation, instrument limitation, and tank inclination are not applicable to this testing method (38). One of the disadvantages of this method is that helium does not flow freely in a liquid; therefore, the tank should be completely empty prior to testing.

Engineering Comments--In this method, the following points may affect testing accuracy:

- Differential temperature response of the reference chamber to actual temperature changes in the tank.

- Pressure change due to unidentified tank end deflection.

- Leakage due to piping and flanges.

In addition, this test cannot provide an actual leak rate under normal conditions, especially when there is a high water table around the tank.

4- TRC Rapid Leak Detector for Underground Tanks and Pipes (39)--

Manufacturer's Description of Method (39)--This method, which is not commercially available, uses volatile and environmentally safe tracers. One to three liters of tracer gas are added to the liquid product. The tracer compound moves from the leaking tank or pipeline through any leak. High-volume pumping in the backfill surrounding the tank draws the tracer from the leak point to a monitoring pipe where the soil gas is sampled and subjected to field chromatographic analysis. The tracer plume is then probed upgradient to locate the leak point.

This method allows remedial measures to be implemented before significant environmental damage has occurred. If more than one system is suspected, different tracers can be used to test several systems at once.

Manufacturer's Techniques to Compensate for Effects of Variables (39)--The testing method can detect leaks only by detection of the tracer gas outside a tank. High-volume pumping is used to speed the tracer gas transfer to the detection points.

Engineering Comments--The TRC Rapid Leak Detector cannot measure leak rate. In addition, due to the presence of product in the tank, ground water, and ground physical characteristics (especially for tanks with clay backfill), the testing may take a long period of time before a small leak can be detected. One of the reasons is that the tracer gas does not flow freely through the liquid (37). However, the method does not require the tank or pipes to be removed from service during the testing.

5- Ultrasonic Leak Detector, Ultrasound (40,41,42,43)--

Manufacturer's Description of Method (40)--Utilization of ultrasound to detect leakage in underground storage tanks is a possibility. For the past 15 years, portable ultrasonic sensors have been utilized to locate pressure and vacuum leakage in a variety of systems such as power plants and chemical plants. The detection probes sense ultrasonic emissions produced by a pressure or vacuum leak. At present, an ultrasound system has not been used for tank leak detection; however, it is a very promising method. Following is a description of the expected system performance.

By plugging all gas vents and draining the fluid from the tank, a vacuum can be produced. The negative gage pressure will draw air into the tank from the soils surrounding the tank wall through the leak site. The entire tank wall can be scanned in seconds because the detection head is directionally sensitive and can be rotated to detect the maximum signal. Piping leaks can be detected at the same time, and leaks can be pinpointed within a spread of 15 degrees from the apex of the transducer. A leak will be noted through headphones worn by the operator as well as being registered on a meter.

The ultrasound detection method requires a compact field unit with headphones and meter. In addition, the system is designed to record test results and the location of a leak. A relatively simple method of airborne ultrasonic leak detection from existing commercially available technology can be adapted to locate in-ground leakage in storage tanks easily and rapidly.

Monitoring equipment setup for this system will be very simple. Once set up, only 20 minutes is required to test a tank. Also, several tanks can be tested simultaneously. The detection system can be designed with sufficient sensitivity to measure a leak rate of 0.001 gallons per hour or greater of air (44). A leak of 0.005 inches in diameter with a pressure differential of five pounds per square inch can be detected over 30 feet away. Therefore, the task of detecting a leak rate lower than 0.05 gallons per hour is straightforward.

Manufacturer's Techniques to Compensate for Effects of Variables (40)--For the Ultrasound System, the following variables are compensated for as described below:

- Water Table--If the water table surrounds the leak hole, it will be detected because the the tank chamber will be in a vacuum state so that the pressure differential between the tank environment and the ingressing water droplets will cause the water droplets to expand and, due to a low surface tension, burst. This burst will produce a detectable ultrasound (between 20 kHz and 100 kHz).

- Piping Leaks--Because the detection head can be rotated to detect maximum signal location, piping leaks will be detected.

- Noise--Because the detection sensor is mounted in a closed system (the tank being tested), background noise in the ultrasonic ranges would not affect the results. In addition, the wave length of ultrasound is relatively short; therefore, it is easily pinpointed in the presence of ambient, audible sounds.

- Equipment Accuracy--Ultrasound can be designed to sense a leak at a rate of 0.001 gallons per hour or greater of air (44). A leak of 0.005 inch in diameter with a pressure differential of five pounds per square inch can be detected.

- Operator Error--The system will be equipped with a meter to register test results; this will minimize or eliminate inaccuracy due to operator error (44).

- Power Variations--This will not affect system accuracy because it will be powered by batteries.

- Instrumentation Limitation--The system can be capable of detecting a leak of greater than or equal to 0.005 inches in diameter with a pressure differential of five pounds per square inch at a distance of 30 feet from the detector.

- Temperature, tank end deflections, vapor pockets, product evaporation, tank geometry, wind, vibration, type of product, atmospheric pressure, and tank inclination do not affect testing accuracy (44).

Engineering Comments--For Ultrasonic leak detecting method, the following are noted:

- No experimental or field testing has been conducted using this system for tank testing. However, the method is a possibility.

- It will not provide an exact leak rate.

- It does not consider the effect of ground water level on the leak rate.

6- VacuTect (Tanknology) (7,10,45)--

Manufacturer's Description of Method (45)--The air pressure above the liquid in the tank is reduced to offset the pressure head of the liquid in the tank. As air is drawn into the tank through a leak, bubble sounds are detected by a hydrophone worn by the operator. Characteristics of the sound permit identification of the leak. The approximate size of the leak can be estimated from the characteristics of the sound.

After sealing the ports from the atmosphere, this method can normally be performed in less than one hour and no waiting time is required before testing.

Manufacturer's Techniques to Compensate for Effects of Variables (46)
--In this testing method, the following effects of variables are compensated for as described below:

- Water Table--When tanks are situated in areas of high water table or the soil around the tank is saturated with water, bubbles will not form or will persist for only a short time. This situation is addressed by auxiliary sensors which detect and measure the ingress of water and indicate water level changes during the test.

- Piping Leaks--In most cases, piping leaks can be identified when the product level is lower than the piping and a "hissing" sound is detected by hydrophone during the test.

- Noise--The system is capable of compensating for background noise during a test. However, potential noise sources should be minimized in the test tank area during the test.

- Type of Product--As long as gas bubbles can be created in the product, the testing method could be used effectively.

- Operator Error--The test can determine leaks by a skilled and experienced operator, even in the presence of a water table around the tank.

- Temperature, tank end deflection, vapor pocket, product evaporation, tank geometry, wind, vibration, power variation, atmospheric pressure, and tank inclination should not affect test accuracy.

Engineering Comments--In the VacuTect testing method, the following points are noticeable:

- Operator experience may affect the accuracy of determining a leak rate.

- When a tank is old or corroded, tank damage or leak enhancement due to a vacuum should be considered.

7- Varian Leak Detector (SPY 2000 or 938-41) (5,7,10,47)--

Manufacturer's Description of Method (5,47)--This method is based upon the rapid diffusivity of helium gas through a leak, surrounding soil, and even concrete and asphalt. An instrument using mass spectrometric techniques monitors helium concentration, which is introduced as a tracer into the tank under 1 pound per square inch pressure. Normal equilibrium time is one hour. If a very small leak is suspected, or if the tank is surrounded by clay, it is recommended that the helium pressure be raised to five pounds per square inch pressure and allowed to equilibrate (dwell) overnight. Helium, due to its small molecular size and surface tension, flows through a given leak more than 50 times faster than gasoline. The method can detect a leak through which a 0.005 gallons per hour of gasoline would leak.

The test is accomplished in two subtests. The first subtest is conducted when the tank is at its normal level; this ascertains whether the tank top, piping, and penetrations are leak free. The second subtest is conducted when the tank is completely empty.

Under most conditions, the test can be performed by moving the gas detector probe over the surface above the tank. If the day is windy or a shorter than one-hour dwell time is desirable, small holes must be drilled through the material above the tank at about six-foot intervals and the probe held in the holes.

As a check of the entire system, in the second subtest, a sensitive differential-pressure gage is manifolded to the tank to determine if there is a pressure loss during the dwell time. A pressure loss of about 0.011 pounds per square inch in 24 hours is equivalent to a leak that would allow a flow of about 0.05 gallons per hour in an average-sized tank.

Manufacturer's Techniques to Compensate for Effects of Variables (5,47)--In this method, the following effects of variables are compensated for as described below:

- Temperature--The method is not significantly affected by temperature change.
- Tank Deformation--The method is not significantly affected by end deflection.
- Piping Leaks--Testing can accurately determine the location and can estimate the depth of the leak before excavation begins. Therefore, piping leaks outside the tank can be identified.
- Wind--If the day is windy, small holes must be drilled through the material above the tank at about six-foot intervals and the probe held in the holes.
- Equipment Accuracy--The helium detector is capable of measuring concentrations as low as one part per million. Pressure differences as low as 0.001 pounds per square inch can be determined.
- Vapor pockets, product evaporation, tank geometry, vibration, noise, operator error, type of product, power variation, atmospheric pressure, and tank inclination do not affect testing capability (48).

Engineering Comments--In the Varian Helium testing method, the following are noted:

- The pressure change due to temperature change is not used to evaluate the leak rate.

- The masking or leak rate reduction effects of the water table cannot be avoided.

- If the surface above the tank is frozen, small holes should be dug to detect helium.

In addition, the system can only provide the maximum leak rate without consideration of the location of the leak in the tank.

Inventory Monitoring

1- Gage Stick (49)--

A simple check is to record product depth with a gage stick at the station's close of business and again at start of day. The longer this period, such as weekends or pump repair servicing, the more accurate the test. Gage sticks currently in use can be read to the accuracy of 1/8 inch. Since gage stick readings will fluctuate slightly because of the angle of the stick when dipped into the tank, the condition of the tank bottom and product creep, gaging of the stick into smaller increments would not increase accuracy. Therefore, the gallonage represented by 1/8 inch is the possible error which will be recorded in the inventory records whenever tanks are gaged. This may result in approximately 12 gallons per 1/8 inch measuring range error for a 10,000-gallon tank (49a).

2- MFP-414 TLG Leak Detector (50)--

The MFP-414 TLG is basically used as an inventory monitoring system. A sensor head is placed at the bottom of the tank (Figures 21 and 22). The sensor is connected via a shielded twisted pair of wires to the Control Unit. The Control Unit is located in a nonhazardous area inside the service station office. The sensor head consists of three pressure transducers referenced to the pressure at the top of the tank; the bottom and middle transducers are used for water detection while the top and middle transducers are used for product density measurement. The absolute pressure at the middle transducer and the density measurement are used to calculate the height of the product.

The electronic Control Unit can be used for monitoring up to six tanks and can be installed more than 1,000 feet from any given tank. The manufacturer indicates that the temperature effect is corrected by density measurement. Accuracies of ±0.25 percent and sensitivity of 0.1 percent of product height in the measurement of the product height are claimed. Also, for the most accurate overall results, for the total volume of product, it is recommended that each tank be calibrated in place to account for any deformities in the tank that may have occurred during installation.

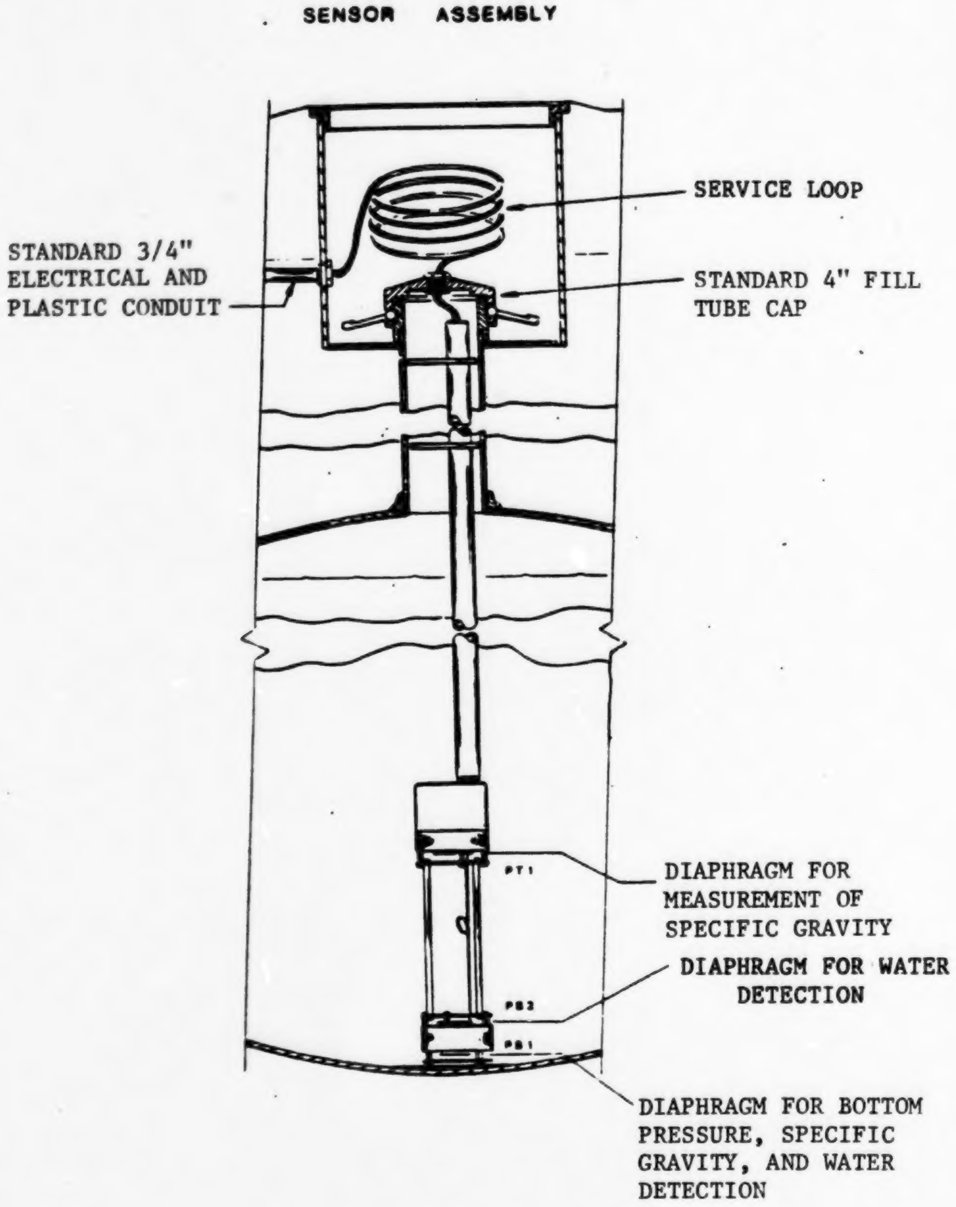

SENSOR ASSEMBLY
SERVICE LOOP
STANDARD 3/4" ELECTRICAL AND PLASTIC CONDUIT
STANDARD 4" FILL TUBE CAP
PT1
DIAPHRAGM FOR MEASUREMENT OF SPECIFIC GRAVITY
DIAPHRAGM FOR WATER DETECTION
PS2
PS1
DIAPHRAGM FOR BOTTOM PRESSURE, SPECIFIC GRAVITY, AND WATER DETECTION

Figure 21. MFP-414 TLG Leak Detector-Sensor Assembly (50)

Ref: Transitron Controls

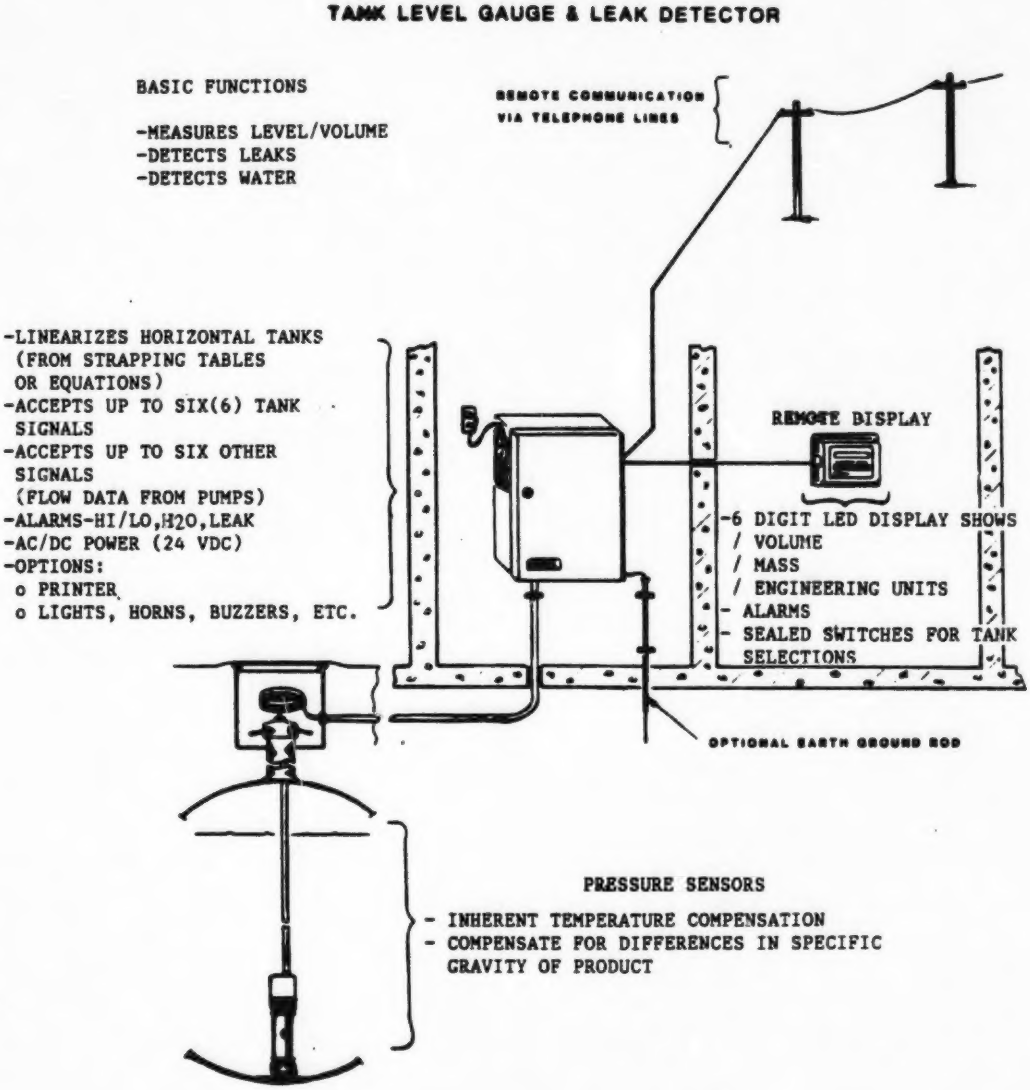

TANK LEVEL GAUGE & LEAK DETECTOR
BASIC FUNCTIONS
-MEASURES LEVEL/VOLUME
-DETECTS LEAKS
-DETECTS WATER
REMOTE COMMUNICATION VIA TELEPHONE LINES
-LINEARIZES HORIZONTAL TANKS (FROM STRAPPING TABLES OR EQUATIONS)
-ACCEPTS UP TO SIX(6) TANK SIGNALS
-ACCEPTS UP TO SIX OTHER SIGNALS (FLOW DATA FROM PUMPS)
-ALARMS-HI/LO,H2O,LEAK
-AC/DC POWER (24 VDC)
-OPTIONS:
o PRINTER
o LIGHTS, HORNS, BUZZERS, ETC.
REMOTE DISPLAY
-6 DIGIT LED DISPLAY SHOWS
/ VOLUME
/ MASS
/ ENGINEERING UNITS
- ALARMS
- SEALED SWITCHES FOR TANK SELECTIONS
OPTIONAL EARTH GROUND ROD
PRESSURE SENSORS
- INHERENT TEMPERATURE COMPENSATION
- COMPENSATE FOR DIFFERENCES IN SPECIFIC GRAVITY OF PRODUCT

Figure 22. MFP-414 TLG Tank Level Gauge & Leak Detector (50)

Ref: Transitron Controls

The system is equipped with a six-digit display that allows an operator to view the total volume or weight of product in each tank in any desired unit of measure. A switch on the display also allows for entering a "SLEEP" mode whereby the tank is monitored for product gain (fill) or loss (theft or leakage). An RS-232C port is provided for connection to a printer, to the station computer/register, or to a modem. The built-in modem support allows for automatic dialing and reporting of alarm conditions (water, leakage, theft) when equipped with an optional modem. This feature also provides a means of remote readout of product inventory from a remote location.

3- TLS-150 Tank Level Sensor (Veeder-Root) (10,51)--

The TLS-150 tank level sensor is a system designed to improve inventory management of nonconductive fluids such as gasoline and diesel fuel in underground tanks. It can monitor up to four tanks to identify inventory losses and accurately reconcile inventories of fuel with dispensing and deliveries.

This system consists of a computerized inventory monitoring with a digital electronic sensing probe for each tank monitored. The system analyzes signals for liquid temperature, liquid depth, and water level. An integral dot matrix printer provides hard-copy documentation.

The TLS system has three modes of operation: leak detection, tank inventory, and automatic delivery reporting. When the leak monitor mode is activated, the system continuously monitors fuel levels in each tank. Also, an hourly report on each tank shows temperature-compensated inventory changes to 0.1 gallons. When a loss of 25 gallons occurs during a one-hour period, an inventory loss alarm initiates a signal.

An optional telecommunications interface allows remote polling of a TLS system from a central management location through a computer or teletype device.

In evaluating TLS system results, a measurement accuracy of ±1.5 degrees Fahrenheit for temperature and ±0.1 inches for level should be assumed. These ranges of accuracies, with tank end deflection, may preclude low leak rate detection with the TLS system.

Techniques to Compensate for Effects of Variables In Inventory Control Leak Detection Tests--To minimize error when using this method to identify a leaking storage tank and to determine the approximate leak rate for major leaks, the following approaches are recommended:

1. American Petroleum Institute publication API 1621, "Recommended Practice for Bulk Liquid Stock Control at Retail Outlets."

2. Inventory records on a daily basis. Failure to do so is often considered by a Fire Marshall sufficient reason to order tests

for leakage. NFPA 30, the Flammable and Combustible Liquids Code, contains an inventory control requirement. This code has been adopted by the Occupational Safety and Health Administration (OSHA) and by 35 states.

3. The National Conference on Weights and Measures allows a legal tolerance of 0.5 percent on gasoline meters. The total of all such unavoidable losses should not exceed one-half of one percent, or five gallons per 1,000 gallons delivered.

4. The system of inventory control should detect discrepancies.

5. Where remote gages are used, accuracy can be verified periodically by checking the tank with stick gages.

6. All tanks must be measured for water levels, especially before and after deliveries. Water gaging is accomplished by applying a water-finding paste to the gage stick.

Leak Effects Monitoring

This class of leak detection methods provides an indirect indication of leakage by evaluating resulting environmental impact. It may be difficult to determine which tank is leaking when there is more than one tank. These methods are likely to be more conclusive than the quantitative testing methods, if no interfering substances are present.

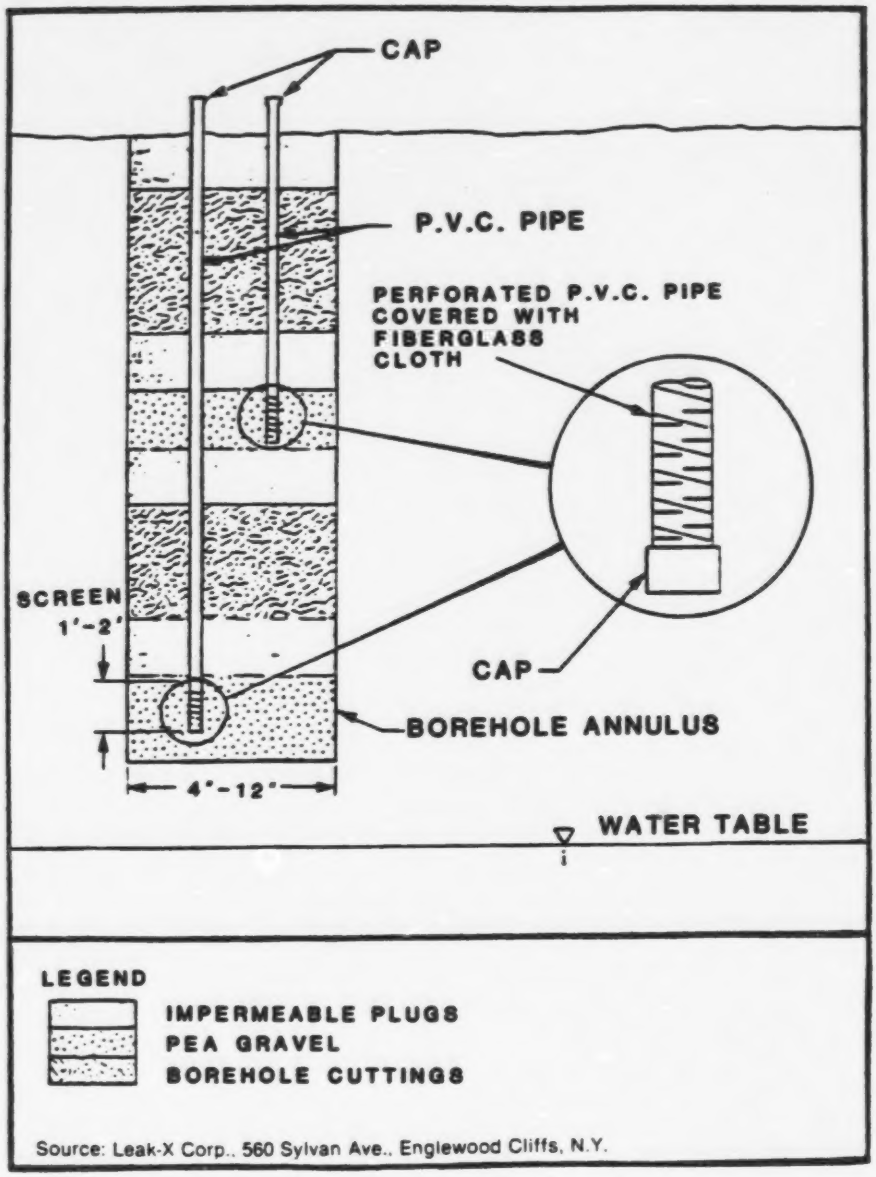
1- Collection Sumps (49)--

Collection sumps can be used in dry hole installations as a collection mechanism which aids in leak detection.

In this type of system, the floor of the storage excavation (or secondary containment liner) is sloped at a rate greater than or equal to 1/8 inch per foot to a collection sump. The sump should be at least two feet deep and be extended to grade via, at a minimum, a four-inch-diameter (Schedule 40) polyvinyl chloride (PVC) pipe and topped with a waterproof cap. This extension is essentially an observation well screened in the region of the sump. The sump should be equipped with a removable leak detection sensor capable of detecting 1/8 inches of standing product, which activates a strategically located aboveground alarm when that product is present. If constructed as described above and shown in Figure 23, the sump and well can also be used for leak sampling and for the recovery of leaked or spilled product.

2- Dye Method (10)--

In this method, a perforated pipe is installed around the perimeter of the underground tank storage area. A bag of dye is connected to the low point of the pipe. The dye is soluble in hydrocarbon and completely


CAP
P.V.C. PIPE
PERFORATED P.V.C. PIPE COVERED WITH FIBERGLASS CLOTH
SCREEN 1'-2'
CAP
BOREHOLE ANNULUS
4"-12"
WATER TABLE
LEGEND
IMPERMEABLE PLUGS
PEA GRAVEL
BOREHOLE CUTTINGS

Source: Leak-X Corp., 560 Sylvan Ave., Englewood Cliffs, N.Y.

Figure 23. Typical Wells For Continuous Gas Or Vapor Monitoring (49)

Ref: Recommended Practices for Underground Storage of Petroleum, New York Department of Environmental Conservation

unaffected by water. The bag is usually checked every day to see if any of the dye has been dissolved.

The installation of the perforated pipe and the length of time to detect small leaks are the drawbacks of this system. In addition, small leaks most likely will not be detected.

3- Ground Water or Soil Core Sampling (10)--

The presence of trace organics can be detected by soil core or water sampling in the vicinity of underground tanks. In both cases, small holes or wells should be drilled. A portable gas chromatograph could be used to analyze samples at the site. When a more precise determination is required, the sample should be analyzed in a laboratory. If a series of wells are drilled at proper locations, the source of the leak may be determined. However, this method cannot distinguish between tank leaks and small spills in the area (usually from poor housekeeping practices).

4- Interstitial Monitoring in Double-Walled Tanks (49)--

Systems which monitor the interstitial space between the walls of double-walled tanks using either vacuum sensors or fluid sensors represent the best mode of continuous leak surveillance available. In such systems, a leak can be detected due to failure of only one of the two walls of the tank. Thus, the operator can be made aware of the leak before stored product has left the tank and entered the environment.

In interstitial leak monitoring system, sensors would be used to monitor tanks that have a vacuum drawn in the space between the tank walls. Failure of either the inner or outer wall is detected by loss of vacuum. Such systems are applicable in either wet or dry hole installations.

Fluid sensors, on the other hand, would be located between the tank walls to detect the presence of liquid due to failure of the inner wall (detecting an outflow of product) or the outer wall (detecting an inflow of water). Such systems are more applicable in wet hole installations where failure of the outer wall will result in the presence of a fluid in the interstitial space. Because failure of the outer wall can go undetected if fluid sensors are used in dry hole installations, such an application is not recommended if pressure sensors can be used instead.

In the case of either type of interstitial monitoring system, it is important that the tank be constructed to allow for free movement of fluids or gases in the space between the tank walls so that a leak anywhere in the tank can activate strategically located sensors.

5- LASP Monitoring System (Leakage Alarm System for Pipe) (52)--

The wall-diffusion effect is the basis for the Leakage Alarm System for Pipe (LASP) system. A one-half-inch-diameter sensor tube is made of a plastic material that allows rapid wall diffusion. The LASP system consists of three components: a flexible sensor tube, a pump, and a detector. The sensor tube can be moved to strategic locations around the tank. The vapors of a leaked product coming in contact with the LASP tube will diffuse into the tube and be captured. At regular intervals (e.g., every 24 hours), a stream of air followed by an injection of a detectable vapor is pumped through the LASP tube. The detector at the end of the LASP tube will register on a line recorder any leakages carried by the air stream, and the regular injection of a detectable vapor will show as an end peak.

6- Observation Wells (49)--

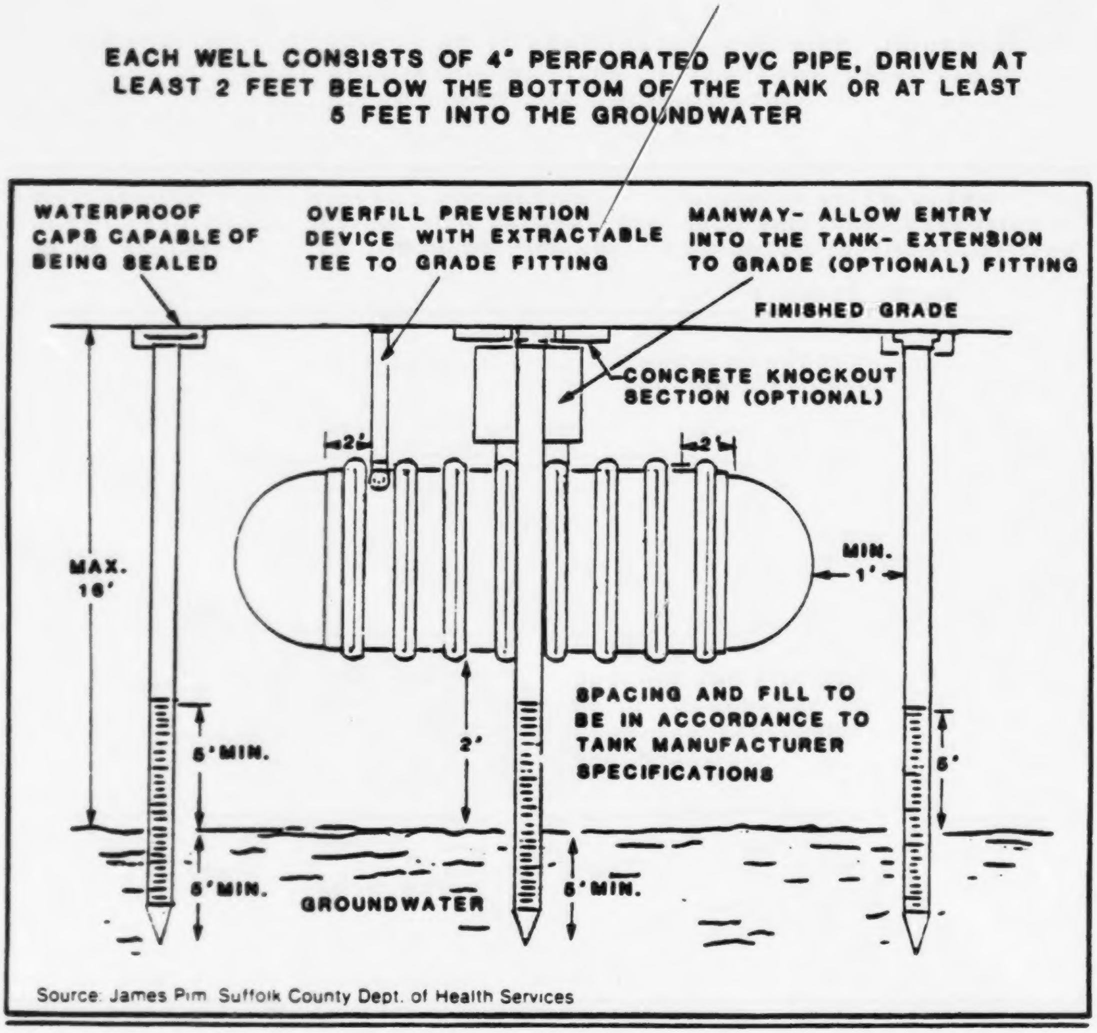
Observation wells are used to monitor for leaks from underground tank installations in areas of high ground water. In this instance, ground water will be present in the excavation for most or all of the year. A diagram of an observation well installation is shown in Figure 24.

An observation well, or liquid product sensing well, consists of, at a minimum, a four-inch-diameter (Schedule 40) PVC pipe placed in the tank excavation. The wells are constructed with a well screen long enough to provide a length of five feet or more above the water table, or to the well cap, and extending a minimum of five feet into the ground water or two feet below the tank bottom, whichever is greater. Well screens typically have a slot size of 0.02 inches. The connecting well pipe is extended to grade and covered with a waterproof cap which is capable of being sealed.

As is true of the vertical section of the U-tube, if observation wells are constructed as described above and shown in Figure 24, they can be used for leak sensing, direct sampling, and product (and contaminated ground water) recovery. When leak sensors are used, they must be capable of detecting a 1/8-inch layer of the stored product on the ground water surface, and they must activate a strategically located aboveground alarm when that product is detected.

The selection of the number and location of the observation wells in a particular storage system is dependent upon the local hydrogeology, including parameters such as the ground water flow direction. It is recommended that any installation using observation wells employ at least two wells in each excavation.

Existing sites may have observation wells drilled to ground water, provided the location and orientation of the tanks and piping is known.


EACH WELL CONSISTS OF 4" PERFORATED PVC PIPE, DRIVEN AT LEAST 2 FEET BELOW THE BOTTOM OF THE TANK OR AT LEAST 5 FEET INTO THE GROUNDWATER
WATERPROOF CAPS CAPABLE OF BEING SEALED
OVERFILL PREVENTION DEVICE WITH EXTRACTABLE TEE TO GRADE FITTING
MANWAY- ALLOW ENTRY INTO THE TANK- EXTENSION TO GRADE (OPTIONAL) FITTING
FINISHED GRADE
CONCRETE KNOCKOUT SECTION (OPTIONAL)
2'
2'
MAX. 16'
MIN. 1'
SPACING AND FILL TO BE IN ACCORDANCE TO TANK MANUFACTURER SPECIFICATIONS
5' MIN.
2'
5'
5' MIN.
GROUNDWATER
5' MIN.

Source: James Pim Suffolk County Dept. of Health Services

Figure 24. Examples Of Observation Wells (49)

Ref: Recommended Practices for Underground Storage of Petroleum, New York Department of Environmental Conservation

7- Pollulert and Leak-X Detection Systems (11,53,54)--

Both detection systems use the significant difference between the thermal conductivity of hydrocarbons and of water to detect leaks. The system's solid-state electronic sensors are placed in a well near the storage tank. The bottom of the well should be at least 10 feet below the bottom of the storage tank. A programmed microprocessor continuously monitors the presence of water or hydrocarbons in the monitoring well. If the sensors detect any hydrocarbons, an alarm sounds. The unit can be wired to automatically summon personnel by telephone.

The major drawbacks of this method are the installation and expense of the monitoring well. However, once the well is installed, if a tank begins to leak, the leak is detected before major damage occurs (unless the leak goes straight down, as happens when ground water is low).

8- Remote Infrared Sensing (10)--

This method depends on the difference in soil temperature due to the presence of hydrocarbons. An infrared sensing device (either an infrared camera or a video system) remotely senses temperatures in the storage tank area. This is usually done from an aircraft rather than at ground level.

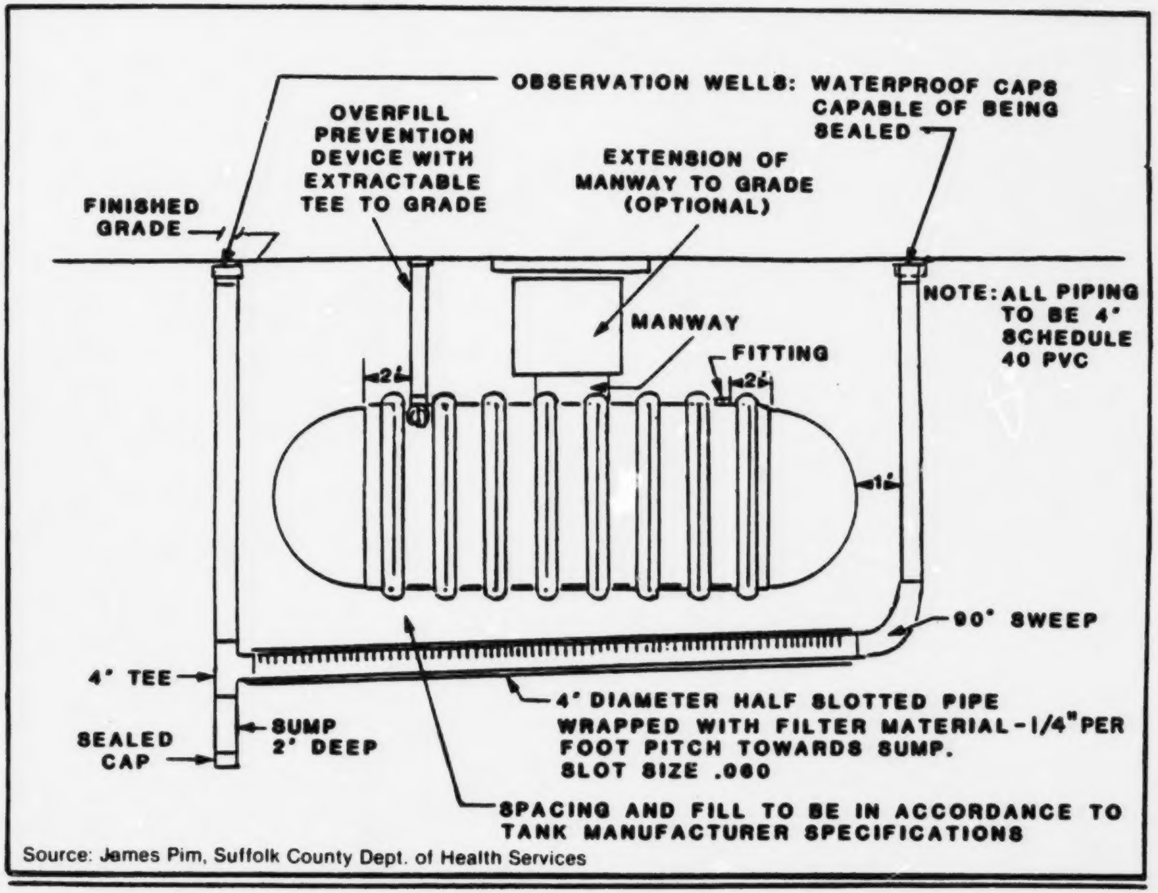
This method is usually only a part of a survey for leak detection; additional ground or subsurface information is required to complete the survey. The ability of this method to detect small leaks is doubtful.

9- Surface Geophysical Methods (10)--

The presence of hydrocarbons in the ground could be determined by using a geophysical method such as ground penetrating radar, electromagnetic induction, or resistivity techniques. These methods are not the primary subject of this text; therefore, they will not be discussed in further detail.

10- U-Tubes (49)--

A U-tube consists of a four-inch-diameter (Schedule 40) PVC pipe installed as shown in Figure 25. The horizontal segment of the pipe is half-slotted (typical slot size, 0.06 inches), wrapped with a mesh cloth to prevent backfill infiltration, and sloped (pitched) toward the sump with a slope on the order of 1/4 inch per foot. At the higher end of the pipe, there is a 90-degree sweep to a vertical pipe that is extended to grade. At the lower end of the horizontal pipe, there is a tee connection with a vertical pipe. Above the tee this vertical section is extended up to grade, and below the tee it is extended down two feet to act as a collection sump. All vertical pipe sections are unperforated, and the bottom of the sump is sealed to be leakproof. All openings to grade are provided with watertight caps capable of being sealed. It is


OBSERVATION WELLS: WATERPROOF CAPS CAPABLE OF BEING SEALED
OVERFILL PREVENTION DEVICE WITH EXTRACTABLE TEE TO GRADE
EXTENSION OF MANWAY TO GRADE (OPTIONAL)
FINISHED GRADE
NOTE: ALL PIPING TO BE 4' SCHEDULE 40 PVC
MANWAY
FITTING
2'
2'
1'
90° SWEEP
4' TEE
SEALED CAP
SUMP 2' DEEP
4' DIAMETER HALF SLOTTED PIPE WRAPPED WITH FILTER MATERIAL-1/4"PER FOOT PITCH TOWARDS SUMP. SLOT SIZE .060
SPACING AND FILL TO BE IN ACCORDANCE TO TANK MANUFACTURER SPECIFICATIONS

Source: James Pim, Suffolk County Dept. of Health Services

Figure 25. Example Of A U-Tube Installation (49)

Ref: Recommended Practices for Underground Storage of Petroleum, New York Department of Environmental Conservation

imperative that these tubes be secured so that products cannot be accidentally delivered into them.

These tubes may be installed under each tank in an excavation, or centrally located in the excavation. In either case, the excavation bottom must be sloped slightly (a minimum of 1/4 inch per foot) toward the U-tube to permit collection of any leaked material.

The collection sump of the U-tube should be equipped with a removable sensing device which is capable of detecting 1/8 inch of standing product or a 1/8-inch layer of product on water. This sensing device is installed so as to activate an alarm which is strategically located aboveground.

If the vertical section of the U-tube is designed as described above and shown in Figure 25, leaked or spilled product can be readily recovered from the collection sump using standard equipment such as a 3-3/8-inch submersible pump. Construction of the vertical section in this manner also permits easy sampling of leaked material to pinpoint the source of a leak. This may be necessary in situations where two or more similar products are stored, such as in an excavation housing both leaded and unleaded gasoline.

U-tubes can be used only in situations where the excavation is above the high level mark of the ground water table (dry hole installations), the excavation has been provided with an impervious secondary containment layer on its floor, and the installation is covered with a waterproof cap. In such cases, any leaked material will eventually find its way to the U-tube's collection sump where it can be detected without water interference.

11- Vapor Wells (49)--

A vapor well is similar to an observation well except that it is intended for monitoring vapors or odors from underground storage systems instead of liquids. Such a well consists of a four-inch-diameter PVC pipe (Schedule 40) installed in the excavation within five feet of the tank. In dry installations, these wells extend to the containment liner on the floor of the excavation. In wet installations, they extend into the ground water.

The well screens in vapor wells should have a slot size of 0.02 inches. In dry hole installations, the screened opening should extend from the containment volume floor to a height of at least five feet. In wet hole installations, the well screen must be long enough to provide a length of five feet or more above the water table and should extend a minimum of five feet into the water table or two feet below the tank bottom, whichever is greater.

Vapor wells can be used only at uncontaminated sites. Once product vapors have entered the well, they will remain there until both their source has been removed (the leak has been pinpointed and repaired) and the well has been purged free of residual vapors. If the well cannot be purged, the vapor well must be either retrofitted with an alternate means of sensing leaked product or abandoned. Figure 23 is a diagram of a typical, dry hole, vapor well.

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APPENDIX

LEAK DETECTION METHODS

MANUFACTURER OR PRACTITIONER PHONE NUMBERS

LEAK DETECTION TESTING METHODS	PHONE NUMBER	CONTACT NAME
Volumetric (Quantitative) Leak Testing Methods		
1 - Ainlay Tank Tegrity Testing (TTT)	(312) 328-6119	Mr. John Ainlay
2 - ARCO HTC Underground Tank Leak Detector	(312) 333-3000	Mr. Gary L. Everett
3 - Certi-Tec Testing	(612) 487-1484	Mr. Jonathan Nedved
4 - "Ethyl" Tank Sentry Testing	(609) 452-8600	Mr. A. V. Morschauser
5 - EZY-CHEK Leak Detector	(517) 684-7180	Mr. John Horner
6 - Fluid-Static (Standpipe) Testing	Method is used by different contractors	
7 - Heath Petro Tite Tank and Line Testing (Kent-Moore Testing)	(617) 344-1400	Mr. Jack Stillwagon
8 - Helium Differential Pressure Testing	(415) 228-8400	Mr. John Schweizer
9 - Leak Lokator Test (Hunter-Sunmark Leak Detection)	(215) 296-7380	Mrs. Donna Hymes
10 - Mooney Tank Test Detector	(504) 241-0453	Mr. Joseph Mooney
11 - *PACE Tank Tester	(416) 443-7032	Mr. Jack Witherspoon
12 - *PALD-2 Leak Detector	(Not Available) 3425 West 30th Ave. Vancouver, B.C., V6S1W3 CANADA	Mr. Werner Grundmann
13 - Pneumatic Testing	Method is used by different contractors	
14 - Tank Auditor	(617) 740-1717	Mr. William E. Baird
15 - *Two-Tube Laser Interferometer System	(415) 424-1251	Mr. Joseph W. Maresca

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*Not commercially available.

LEAK DETECTION TESTING METHODS	PHONE NUMBER	CONTACT NAME
Nonvolumetric (Qualitative) Leak Testing Methods		
1 - *Acoustical Monitoring System (AMS)	(615) 966-4773	Mr. Charles B. Oh
2 - Leybold-Heraeus Helium Detector, Ultratest M2	(412) 327-5700	Mr. William C. Worthington
3 - Smith & Denison Helium Test	(415) 782-9788	Mr. William H. Burkhart
4 - TRC Rapid Leak Detector for Underground Tanks and Pipes	(602) 623-0200	Mr. Glenn Thompson
5 - *Ultrasonic Leak Detector, Ultrasound	(914) 592-1220	Mr. Mark A. Goodman
6 - VacuTect (Tanknology)	(403) 483-3506	Mr. Edward Adams
7 - Varian Leak Detector	(617) 935-5185	Mr. Roger Schneider
Inventory Monitoring		
1 - Gage Stick	Method is used by different contractors	
2 - MFP-414 Leak Detector	(617) 238-6911	Mr. Stanley Hayes
3 - TLS-150 Tank Level Sensor (Veeder-Root)	(203) 527-7201	Mr. Tony Spera
Leak Effects Monitoring		
1 - Collection Sumps	Method is used by different contractors	
2 - Dye Method	Method is used by different contractors	
3 - Ground Water or Soil Core Sampling	Method is used by different contractors	
4 - Interstitial Monitoring in Double-Walled Tanks	Method is used by different contractors	
5 - L.A.S.P. Monitoring System	(214) 271-2561	Industrial System Marketing
6 - Observation Wells	Method is used by different contractors	
7 - Pollulert and Leak-X Detection Systems	(317) 856-3857 (212) 822-6767	Mr. Dale McClain (Pollulert) Mr. John Gelles (Leak-X)

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*Not commercially available.

LEAK DETECTION TESTING METHODS	PHONE NUMBER	CONTACT NAME
8 - Remote Infrared Sensing	Method is used by different contractors	
9 - Surface Geophysical Methods	Method is used by different contractors	
10 - U-Tubes	Method is used by different contractors	
11 - Vapor Wells	Method is used by different contractors	

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*Not commercially available